Evaluation of the SpeechViewer Computer-based Speech Training System with Neurologically Impaired Individuals

Évaluation du système informatisé de la parole SpeechViewer avec des personnes souffrant de troubles neurologiques

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Key Words: computer, dysarthria, speaking rate, speech, intelligibility

Abstract

There are few research studies documenting the effectiveness of Computer-Based Speech Training (CBST) systems. This paper evaluates the effectiveness of the IBM SpeechViewer CBST combined with a newly developed rate control program (The Stepping Stones Game) for improving speech production in individuals with dysarthria. Three subjects were studied using a single-subject multiple baseline design. Voice timing, speaking rate, and vowel accuracy were trained sequentially. Dependent measures included: speech intelligibility, speaking rate, and acoustic measures obtained on the selected speech parameters. Four of the six multiple baseline treatment phases analyzed statistically revealed significant training effects. The other two phases revealed trends towards normal values. Results indicate that for the three subjects studied the SpeechViewer and the Stepping Stones Game were effective tools for modifying speech attributes and improving intelligibility.

Résumé

Il y a eu peu d'études de l'efficacité des systèmes informatisés d'éducation de la parole. L'article évalue l'efficacité du système SpeechViewer d'IBM combiné avec un nouveau programme de contrôl du débit (Stepping Stones Game) pour améliorer la production verbale chez les personnes souffrant de dysarthrie. On a étudié trois sujets à l'aide d'un modèle de base multiple pour un sujet unique. On a fait consécutivement l'éducation du minutage de la parole, du débit de la parole et de l'exactitude des voyelles. On a notamment utilisé les mesures dépendantes suivantes: intelligibilité de la parole, débit de la parole et mesures acoustiques obtenues sur certains paramètres de la parole. Quatre des six phases du traitement de base multiple ont produit des effets significatifs de l'éducation sur le plan statistique. Les deux autres phases ont révélé des tendances vers les valeurs normales. Les résultats indiquent que, pour les trois sujets étudiés, le SpeechViewer et le Stepping Stones Game ont été des instruments efficaces pour modifier les attributs de la parole et améliorer l'intelligibilité.

Dysarthria is a neuromuscular motor speech disorder that can range in severity from a disorder so mild that it is just noticeable during connected speech, to a disorder so severe that no functional speech is present. Dysarthria is present in approximately 33% of all patients with traumatic brain injuries (Sarno, Buonagura, & Levita, 1986); 68% of individuals with cerebral palsy (Hopkins, Bice, & Colton, 1954); and varies from 19% to 100% in individuals with degenerative neurological diseases, such as Multiple Sclerosis, Parkinson's Disease, and Amyotrophic Lateral Sclerosis (Darley, Brown, & Goldstein, 1972; Logemann & Fisher, 1981; Darley 1978). Dysarthria often results in reduced speech intelligibility. Individuals with reduced speech intelligibility experience difficulties with social interaction, academic performance, and vocational placement (Simon, 1985). Improving speech intelligibility is the primary clinical goal with dysarthric speakers (Yorkston, Beukelman, & Traynor, 1984). For mild dysarthric speakers, the goal may shift to maximizing speech naturalness, while maintaining intelligibility (Yorkston, Beukelman, & Bell 1988).

Computer-Based Speech Training (CBST) has considerable potential for enhancing clinical practice in this area. These systems provide visual feedback on aspects of speech, such as pitch, loudness, voicing, and vowel productions. They also allow the clinician to obtain objective measures of speech production. The visual feedback helps patients develop insight into their speech difficulties and may increase the efficiency of the remediation process.

There are few studies documenting the effectiveness of CBST (Bernstein, Goldstein, & Mahshie, 1988). Only 5-10% of CBST systems have been tested in controlled experiments, and few of these systems have been tested by investigators other than their developers (Watson & Kewley-Port, 1989). One reason for the scarcity of such research is that it is often the most time-consuming and labour intensive aspect of CBST development. Unless carefully collected data support the substitution of computer-based feedback for human judgement, the use of such systems clearly might do more harm than good (Watson, Reed, Kewley-Port, & Maki, 1988).

Clinical application of the SpeechViewer has shown strong indications of clinical effectiveness for speech training (International Business Machines, 1989; Thomas-Stonell, 1990), however, there is little controlled research supporting SpeechViewer's use as a speech training tool. Pilot studies evaluating the SpeechViewer are just beginning to emerge (ASHA Speech Foundation, 1989; Ryalls, Cloutier, & Cloutier, 1991). The purpose of the present study was to evaluate the effectiveness of the SpeechViewer system and associated Stepping Stones Game for improving speech production in neurologically-impaired individuals.

Methods

Subjects

Three dysarthric subjects whose average word and sentence intelligibility scores were between 20 and 90% (Yorkston, et al., 1984) participated in the study. All three subjects, age 5, 17, and 18 years, had obtained their formal education in English. All subjects had normal hearing, were able to follow directions, and demonstrated some insight into the remediation process.

Design and Procedures

A single subject multiple baseline design with counterbalancing and replication was used in this study (McReynolds & Kearns, 1983). This design was selected because the behaviours to be trained were not expected to return to baseline after the training period and, therefore, would not be reversed for ethical reasons. The baseline phase provided indications of any spontaneous recovery. Control is demonstrated by replication of treatment effects across behaviours and subjects (McReynolds & Kearns, 1983).

The behaviours were three speech attributes judged to be important contributors to speech intelligibility and naturalness: voice timing, speech rate, and vowel accuracy. Selection of these behaviours was based on assessments completed during the baseline phase of the study and on clinical judgement. Assessments included articulation testing, oral-peripheral examinations, maximum phonation times, aerodynamic measures, and preliminary acoustic analysis of speech. Aerodynamic testing involved dynamic measures of intraoral pressure and combined oral and nasal flow rates during repetition of the syllable "pa" as described by Smitheran and Hixon (1981). The behaviours were also selected to be trainable either with software already included with the SpeechViewer or the newly developed computer-based rate control game, The Stepping Stones Game (Thomas-Stonell, McClean & Dolman, 1991).

The goal of the Voice Timing training phase was general improvement of laryngeal control for both voiced and unvoiced sounds, including voice onset times (VOT) for voiceless plosives. Voice timing was taught using the Voicing Onset Awareness, Voicing Skill Building, and the Pitch and Loudness Patterning modules of the SpeechViewer. In the Voice Awareness module, a train is moved across the screen at the onset of each voiced sound. The time taken for the train to move through the entire screen is displayed in the bottom corner. A faster time indicates increased laryngeal control. The Voicing Skill Building module consists of a pattern of mountains (which represent voiced sounds) created by the clinician. Decreasing the distance between the mountains reduces the amount of time available to turn the voice off and on again and requires greater laryngeal control. The Loudness portion of the Pitch and Loudness module displays speech phrases on a horizontal axis. The speech pattern is red for voiced sounds and green for voiceless sounds. The amount of green displayed at the onset of voiceless plosive words corresponds to voice onset times.

Rate training was conducted using the Stepping Stones Game (Thomas-Stonell, McClean & Dolman, 1991). Individual target utterances were designed according to clinical goals (i.e., increase or decrease speech rate) and represented as a series of stones which form a path to an island. The stepping stones correspond to the pauses in the target sentence. To successfully cross to the island, children must match the temporal pattern of the target utterance.

Vowel productions were trained using the Spectra Patterning, Vowel Accuracy Skill Building, and Vowel Contrasting Skill Building modules of SpeechViewer. The Spectra module allows a target sound spectrum to be frozen on the screen. A live action spectral display, shown as a different colour, allows clients to experiment with different articulator positions to produce a vowel sound closer to the target spectrum. This module was used in the initial phases of vowel accuracy training. Once a close match was achieved with this module, training progressed to the Vowel Accuracy module that requires a matching target sound to be within an accuracy threshold. This threshold level, set by the clinician, can be adjusted gradually to require increasingly accurate vowel productions. Once consistency was reached with this module, training progressed to the Vowel Contrasting module. This module requires that the client produce 4 different vowel sounds to steer a cursor through a maze. This module was used in the final phase of training because it requires clients to alternate between vowel productions accurately.

Speech attributes were trained sequentially. Within subjects, baseline and training phases were of equal length. For Subjects 1 and 3, the order of training was: Voice Timing, Speaking Rate, and Vowel Accuracy. Subject 2 received training in the reverse order: Speaking Rate and Voice Timing. This subject did not require training on the third attribute. Speech sessions were scheduled three times a week for a total of 24-36 sessions per subject. Training sessions were 45 minutes in length.

Statistical Analyses

An innovative extension of the multiple baseline design was used for statistical analysis (Ottenbacher, 1986). The dependent measures were speech intelligibility and speaking rate as measured by the *Computerized Assessment of Intelligibility of Dysarthric Speech* (CAIDS) (Yorkston et al., 1984) and by acoustic measures of voice onset time, vowel duration, and sentence duration. The CAIDS test was administered at the beginning and end of the baseline phase and after each intervention period. Multiple data points were not obtained from the CAIDS test (intelligibility and rate information) during each phase. Therefore, statistical analysis was not performed on this data. Rather, data were graphed and interpretations drawn from these graphs (see Figure 2). The acoustic measures (described below) were obtained from a taped speech sample (see Appendix A) administered at regular intervals throughout the study. These measures were evaluated over time and graphically compared to data obtained from normal speaking peers. All normal speaking peers were obtained from The Hugh MacMillan Rehabilitation Centre during the study. The normal speaking peers completed the same speech sample as the subjects. They were measured once and mean results extrapolated throughout all treatment phases. Values obtained were checked against tabulated norms to ensure their appropriateness (Baken, 1987).

Multiple data points for each acoustic measure were obtained during the baseline and treatment phases. In order to apply a within subject *t*-test analysis across treatment phases on the acoustic data obtained from the speech sample, the assumption of independence of each observation is needed. Results of a runs test confirmed the independence (lack of serial correlation of data) between observations during each phase of the study (Daniel, 1978). Two separate analyses were completed. The first analysis (multiple baseline analysis) used all treatment phases previous to the given phase as baseline. This means that a protracted baseline was used as a comparison for data obtained during phases two and three. The second analysis (single baseline analysis) treated each phase independently, and results were compared only to the initial baseline phase. The results of the multiple baseline *t*-test analysis are presented in Table 1 and the data graphed in Figures 1, 3, and 4. The results from the non-multiple baseline analysis are given in Table 2. The p values should be interpreted with caution because of the accumulated experiment-wise error due to performing multiple *t*-tests and the assumption of the independence of the data based on the runs test.

Acoustic Analysis

Acoustic analysis of subjects' speech patterns can provide sensitive measures for baseline assessment and evaluation of the effects of speech therapy with dysarthric speakers (Till & Toyle, 1988). A standard speech sample (see Appendix A) and protocol for acoustic analysis were developed. The speech sample included single words and sentences that were tape recorded on an Akai Model GX-270D. A speech wave analysis program from GW Instruments (Cambridge, Mass) was used to analyze the tape recordings on a MacIntosh II computer. Recorded signals were played back on a Teac Model X-300 recorder and digitized at a sampling rate of 10 KHz after low-pass filtering at 4.5 KHz.

Measures were obtained on voice onset time (VOT), vowel duration, and total utterance duration. Vowel duration and VOT measures were obtained from waveform displays. Vowel onset and offset were measured from the onset and offset of periodicity in the waveforms. All timing measures were made to the nearest millisecond. Voice onset times were obtained from three separate productions of the */p/, /t/* and */k/* phonemes in initial word position. VOT for single word and sentence productions were analyzed separately. VOT was measured from the onset of the stop release burst to the onset of periodicity in the waveform. The waveform display was expanded to 1 ms time segments for these measurements.

Results and Discussion

Subject 1

Subject 1 was an 18 year old female who had dysarthria subsequent to a closed head injury accident. She was six months post-injury at the start of the study. Prior to training, single word intelligibility was 78%. Sentence intelligibility was 95.9% (average intelligibility = 87%) with a speaking rate of 44.5 wpm. Voice quality was breathy. Breath support for speech was reduced. Aerodynamic testing revealed reduced oral pressures and elevated airflow rates. Speech was characterized by reduced pitch and vocal intensity, an equalized stress pattern (scanning speech), and reduced speaking rate.

All phonemes were produced correctly in single words, but occasional reductions of consonant clusters and final consonant deletions were noted in conversational speech.

The goal of speech training during the Voice Timing phase was to improve laryngeal control and reduce abnormally long VOT during voiceless plosive productions (see Figure 1). The goal of Speech Rate training was to increase speech rate, while maintaining sentence intelligibility over 95% (optimal speech rate). CAIDS testing revealed difficulty producing short and r-coloured vowels. Vowel Accuracy training focused on these vowel sounds.

Results for Subject 1

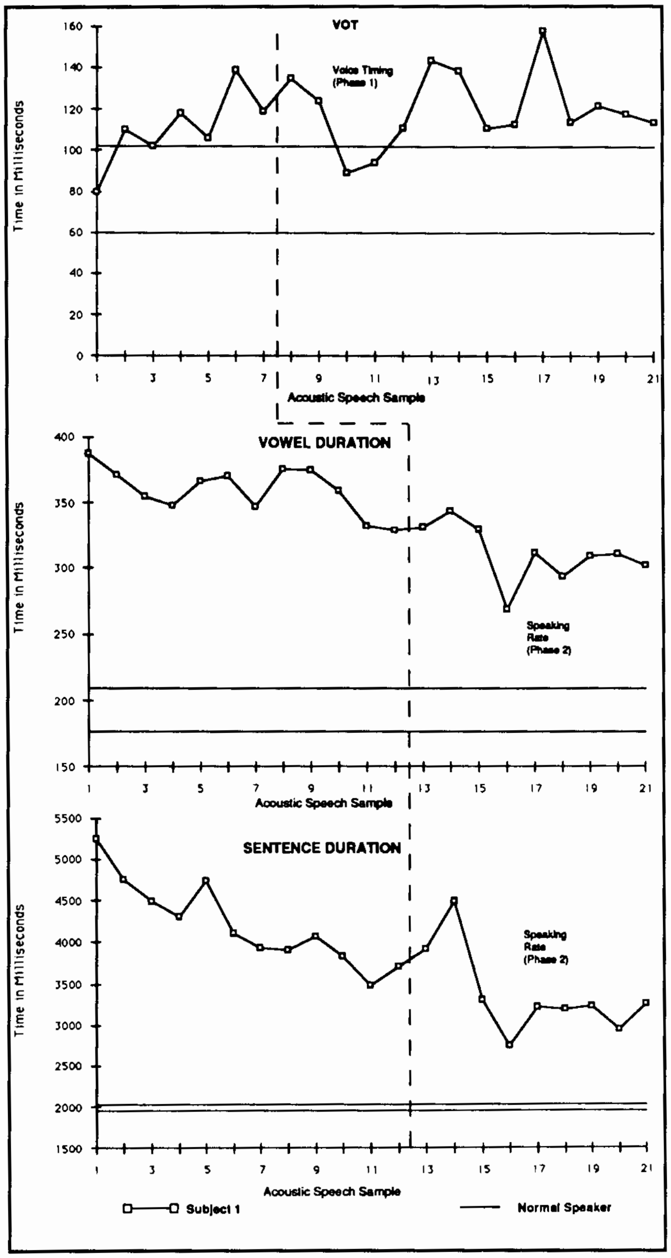
As shown in Figure 1, mean VOT (sentence level) lengthened during the baseline phase. This trend was reversed during the Voice Timing training phase. VOT appeared to stabilize during the Vowel Accuracy training phase slightly below initial baseline levels. Although there was a change of direction toward normal values during the training phase, the changes were not statistically significant. VOT (word level) was not analyzed statistically because baseline values were within the range of values obtained from the normal speaking peers.

Speaking rate was measured by the CAIDS. Vowel duration and overall sentence duration measures were obtained from the speech sample. A significant reduction was noted in vowel duration both for words ($p = 0.03$) and sentences ($p = 0.006$) during the rate training period. Changes in sentence duration were not significant within the rate training phase but were significant ($p = 0.005$) when baseline was compared to the mean sentence duration from all 3 training phases. The greatest change in sentence duration was noted during the rate training phase. Overall intelligibility improved throughout the training period (see Figure 2). Single word intelligibility improved from 78% (beginning baseline) to 94%. Sentence intelligibility improved from 95.9% to 99.1%. Speaking rate as measured by the CAIDS improved from 44.5 wpm (beginning baseline) to 73.7 wpm at the completion of the study.

Discussion of Subject 1

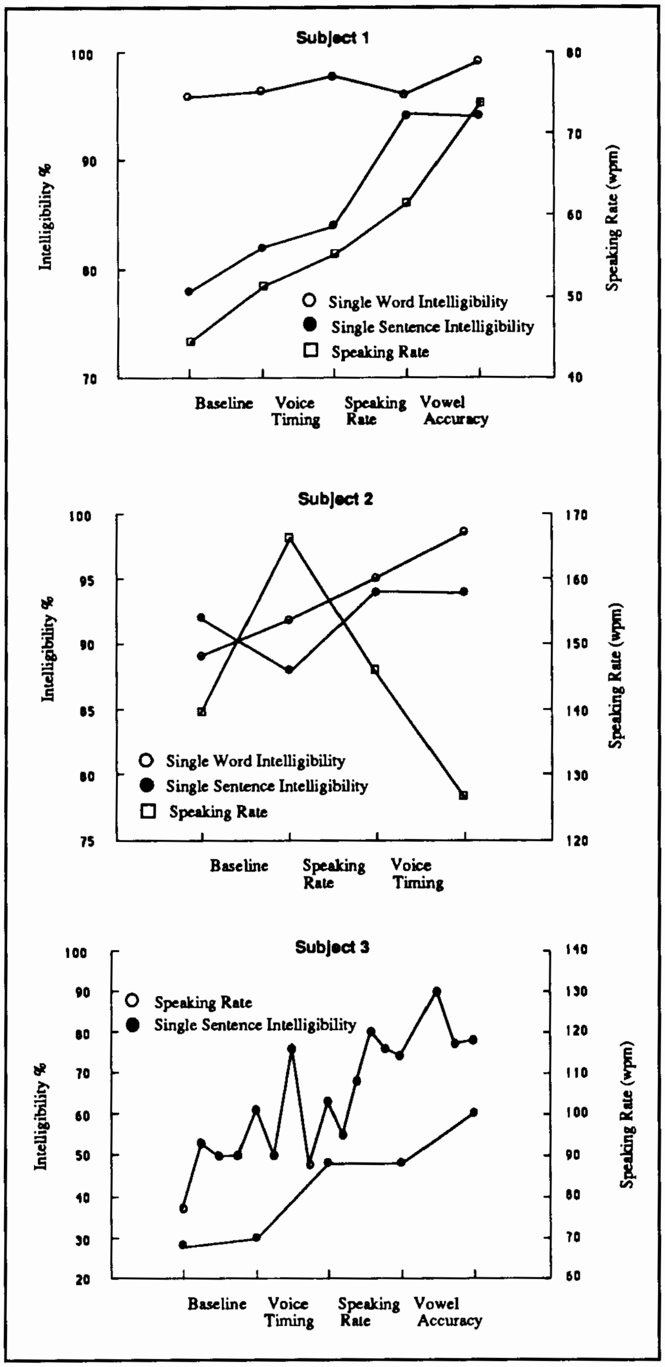
Although changes in VOT were not significant during the Voice Timing phase, there was a change of direction toward normal values. The lack of significance during this phase can be attributed at least in part to the rising, non-stable baseline and the high variability in VOT productions. A 10% increase in single word intelligibility was observed during the rate training phase. This likely reflects improved vowel quality caused by the significant shortening of vowel durations during this phase. The Stepping Stones Game requires

Figure 1. Mean acoustic measures obtained from the speech sample during the first two phases of speech training for subject 1: Voice Timing Phase - VOT for voiceless plosives (Sentence Level) and Speaking Rate Phase - vowel duration (Word Level). Also indicated are the mean acoustic measures obtained from the speech sample for two normal speaking peers.



matching of articulation time, in order to land on the stepping stones. A recent study by Yorkston, Hammen, Beukelman, and Traynor (1990) noted a decrease in vowel intelligibility of more than 10% in over half their subjects as a result of slowing speech rate. This was attributed to an increased number of diphthong vowel productions at the slowed rate. In this study an increase of 10% intelligibility was noted in association with reduced vowel durations.

Figure 2. Intelligibility scores and speaking rates obtained from CAIDS testing of subjects 1, 2 and 3 at baseline and after each of the three training phases: Voice Timing; Speaking Rate and Vowel Accuracy. [The graph for subject 3, shows additional data points for speaking rate since it was obtained from the speech sample rather than the CAIDS test].



The most significant change in speaking rate was noted during the Vowel Accuracy training phase. Changes in rate were twice that of previous phases. This may have resulted from a stabilization of rate skills acquired in the previous phase or an interaction of rate and vowel training effects. Sentence intelligibility increased from 95.9% to 99.1% during this phase, possibly reflecting increased consistency in productions at the sentence level.

Subject 2

Subject 2 was a 17 year old male with mild dysarthria subsequent to a closed head injury accident. He was also 6 months post-injury at the start of the study. Prior to training, single word intelligibility was 92% and sentence intelligibility was 89% (average intelligibility = 90.5%). Speaking rate was 145.9 wpm. Voice quality was slightly breathy, but aerodynamic testing revealed normal levels of oral pressure and airflow rate. Speech was characterized by consonant imprecision, reduced VOT, accelerated speech rate, and slightly reduced pitch and loudness ranges. During oral reading activities and conversation, speech was slurred and indistinct with many hesitations, interjections, and revisions.

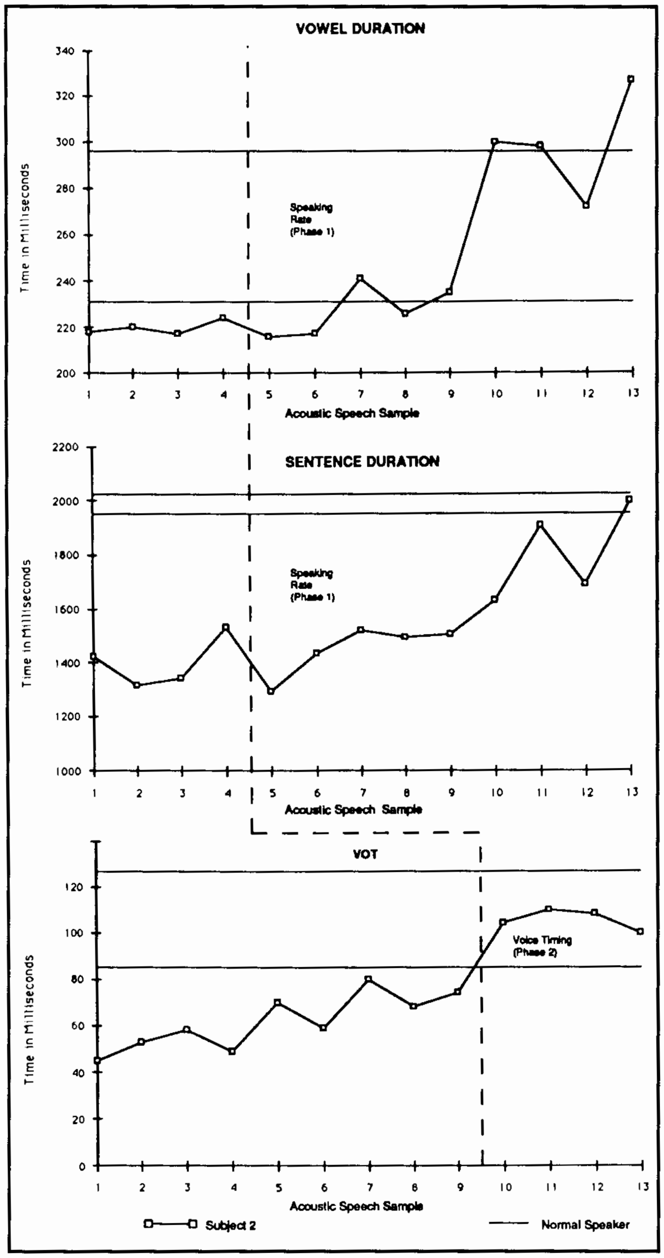
The goal of the Speech Rate training phase was to reduce speaking rate and maximize intelligibility, while preserving the prosodic features of speech. The Voice Timing phase focused on lengthening abnormally short voice onset times (see Figure 3) during production of voiceless plosives. An analysis of perceptual confusions from the CAIDS confirmed that voiceless plosives were consistently perceived as voiced plosive sounds.

Results for Subject 2

During the baseline phase, speaking rate as indicated by CAIDS increased from 140 wpm to 166 wpm (see Figure 2). After rate training, speaking rate was reduced to 146 wpm. A significant increase in vowel durations (word: $p = 0.003$) was noted during the rate training period (see Figure 3). Changes in sentence duration were not significant during the training phase, but did increase toward normal values during this period. As with Subject 1, overall sentence duration was significant ($p = 0.008$) when baseline was compared to both training phases. Changes in VOT were found to be significant at both the word and sentence levels (word: $p = 0.001$; sentence: $p = 0.002$). VOT training was associated with greater increases in sentence duration than in the rate training period. Decreases in speech rate continued to be noted during the Voice Timing training phase. By the end of this phase, speech rate (CAIDS) was reduced to 127 wpm.

Overall, intelligibility improved throughout both training phases of the study. Single word intelligibility decreased from 92% to 88% during baseline, but began improving during the rate training phase and by the end of the study was at 96%. Sentence intelligibility improved from 89% to 98.6%.

Figure 3. Mean acoustic measures obtained from the speech sample during the two phases of speech training for subject 2: Speaking Rate Phase - vowel duration (Word Level) and Voice Timing Phase - VOT for voiceless plosives (Word Level). Also indicated are the mean acoustic measures obtained from the speech sample for two normal speaking peers.



Significant training effects were noted on all the acoustic measures when the baseline data was compared to both the training phases.

Discussion of Subject 2

Statistical analysis of acoustic data obtained from the taped speech sample revealed significant increases in vowel duration (word level) during the Speaking Rate training phase. Increases in sentence duration were also noted, although they were not statistically significant. The greatest change in sentence duration was associated with the Voice Timing training phase. Changes in sentence duration during this phase were 2 1/2 times greater than those achieved during the Speech Rate training phase. This may have resulted in part from the stabilization of skills which were emerging during the Speaking Rate phase added to the significantly lengthened VOT achieved during the Voice Timing phase. Vowel durations also increased during this phase. Speech training techniques during this phase prompted subject 2 to use "slow easy word onsets". Results suggest that subject 2 increased the length of the entire word, since both VOT and vowel durations increased (see Figure 3).

Subject 3

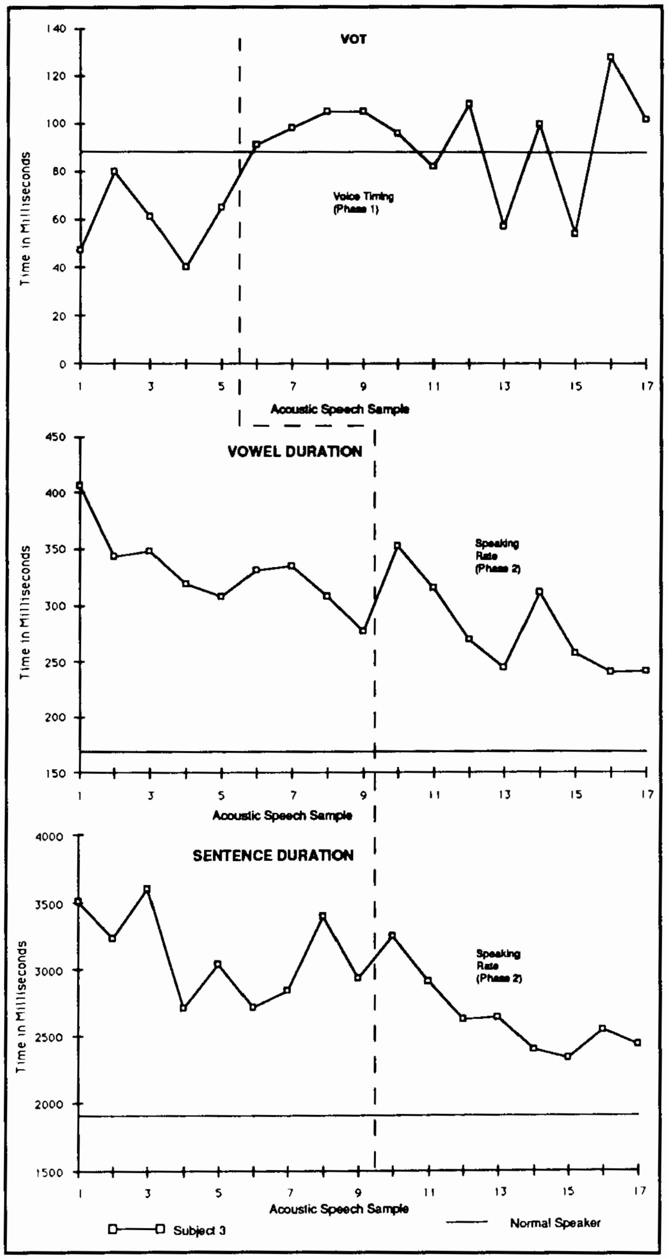
Subject 3 was a 5 year old boy who had severe dysarthria subsequent to myotonic dystrophy. Prior to training, single word intelligibility was 28%. Vocal intensity was extremely variable, even within single word productions. Vocal quality was characterized by intermittent aphonia associated with laryngeal tension and occasional glottal fry. Breath support for speech was reduced. Aerodynamic testing revealed that oral pressures and airflow were within normal levels. Rate of syllable production was extremely slow, approximately 60 syllable/min. The results of aerodynamic testing suggested difficulties coordinating respiratory and laryngeal control for repetition of syllables. Articulation was characterized by developmental consonant sound errors (/r/, /l/, /th/), difficulty producing affricate sounds, simplification of consonant clusters, fronting of velar plosives, and errors in vowel production. During connected speech, subject 3 tended to continue voicing between word segments, which lowered sentence intelligibility. All of the above factors exhibited variability within and across speech sessions.

The goal for the Voice Timing training phase was to improve laryngeal control (timing of voicing and respiration) and increase consistency in VOT. Speech Rate training focused on increasing speech rate, while maintaining or improving intelligibility. Pauses were inserted between words to prevent continuous voicing, while articulation time was reduced by encouraging short, quiet word productions. Vowel Accuracy training focused on both short and long vowels.

Results for Subject 3

During the Voice Timing training phase, significant lengthening of VOT (sentences: $p = 0.01$) was noted as well as greater consistency in production (see Figure 4). Due to difficulties in obtaining acoustic measures on this subject, VOT results were based only on the analysis of productions at the

Figure 4. Mean results obtained from the acoustic speech sample during the first two phases of speech training for subject 3: Voice Timing Phase - VOT for voiceless plosives (Sentence Level) and Speaking Rate Phase - vowel duration (Sentence Level). Also indicated are the mean acoustic measures obtained from the speech sample for a normal speaking peer.



sentence level. VOT were difficult to measure because of the introduction of noise (breathing sounds, hoarseness, roughness) into the speech sample. CAIDS testing revealed an 18% increase in intelligibility during this training phase. As indicated in Figure 4, improvements in VOT were not maintained after the training phase, although gains in intelligibility were maintained.

Changes in the mean vowel duration (sentences) during the rate phase were not significant; however, changes toward normal values were noted in all three phases. Reductions in vowel durations at both the word and sentence levels were significant (word: $p = 0.02$; sentence: $p = 0.03$) when baseline was compared to all the training phases. Similarly sentence duration was not significant within the rate phase, but was significant ($p = 0.02$) when compared to all three training phases.

Overall intelligibility improved from 28% to 60% throughout the study (see Figure 2). An 18% gain was noted during the Voice Timing training phase and a further 12% gain was achieved during the Vowel Accuracy training phase. Speaking rate was measured by timing the sentence portion of the speech sample. Average speaking rate prior to training was 88 wpm or 94 syl/min, compared to the average speaking rate for preschool children of 179 syl/min (range of 139-226) (Pindzola, Jenkins, & Lokken, 1989). Speaking rate by the end of training had increased to 120 wpm. Significant training effects were noted on all dependent measures when the baseline phase was compared to combined measures from the three training phases.

Discussion of Subject 3

In addition to the significant changes in VOT achieved during the Voice Timing phase, an 18% increase in single word intelligibility was noted. Significant lengthening and greater consistency of VOT production and improved voice quality resulting from decreased aphonic breaks may have contributed to improved speech intelligibility.

Reductions in vowel duration were noted throughout each training period. There was a tendency for these reductions to be lost temporarily whenever a new training parameter was introduced. Analysis of sentence durations revealed consistent reductions throughout the Speaking Rate phase. Lack of significance within the rate phase likely was due to the large amount of variability in the baseline data.

All dependent measures were significant when baseline was compared to all three training phases. This significance likely reflects a generalized training effect because spontaneous speech improvement is not expected given the nature of myotonic dystrophy (Allen & Paulson, 1970).

General Results

There were a total of eight multiple baseline treatment phases across the three subjects. Six of the phases were analyzed statistically. The data from the two Vowel Accuracy phases were not analyzed. Acoustic measures were available for only one of the subjects because subject 2 did not require vowel accuracy training and acoustic measures for subject 3 could not be obtained because of the severity and variability of speech productions. It was felt that data from only one subject were too preliminary for analysis. In four of the six treatment phases that were analyzed statistically, at least one dependent measure differed significantly from baseline (see Table 1). The dependent measures from the other two phases showed trends towards normal values.

There were a total of 13 dependent measures corresponding to the multiple baseline phases. Six of the 13 measures were significant within the multiple baseline phases. Ten of the 13 measures were statistically significant when the treatment phases were combined and compared to baseline (see Table 2). All dependent variables for subjects 2 and 3, were significant. Only one of the dependent measures was significant for subject 1. The dependent variables pertaining to the Voice Timing and Speaking Rate phases revealed trends towards normal values, but were not significant.

General Discussion

VOT and speaking rate were both increased and decreased depending on the clinical goals of the subjects. Treatment effects were replicated both within and across subjects. Similar patterns were noted for each of the three subjects, even though the etiology and severity of the dysarthrias were different. Two of the three subjects acquired dysarthria subsequent to closed head injury accidents and might be expected to show some spontaneous recovery. The baseline phase of the multiple baseline design provides indications of any spontaneous recovery. Control is demonstrated when the target behaviors change significantly during the training phase. For these two subjects, three of the four treatment phases differed significantly from the baseline phase according to at least one dependent measure. This result is generally attributable to treatment effects. For Subject 3, no spontaneous recovery was expected. Training effects could be examined both within and across the multiple baseline treatment phases. While only one of the multiple baseline training phases

Table 1. Summary of experimental results multiple-baseline analysis.

	Baseline Mean (ms)	Treatment Mean(ms)	*p*
Subject 1			
Voice Onset - Word	N/A		
Voice Onset - Sentence	110.6	110.6	0.99
Vowel Duration - Word	412.7	380.0	0.03
Vowel Duration - Sentence	359.6	318.5	0.006
Sentence Duration	4213.4	3615.2	0.09
Subject 2			
Voice Onset - Word	61.8	105.5	0.001
Voice Onset - Sentence	51.9	67.2	0.002
Vowel Duration - Word	218.7	234.0	0.003
Vowel Duration - Sentence	175.2	176.3	0.78
Sentence Duration	1390.0	1506.0	0.07
Subject 3			
Voice Onset - Word	N/A		
Voice Onset - Sentence	57.0	100.3	0.01
Vowel Duration - Word	424.9	352.8	0.06
Vowel Duration - Sentence	330.6	295.8	0.17
Sentence Duration	3109.4	2856.0	0.22

Note: N/A = data not amendable to analysis;
Statistical significance indicated by $p<0.05$

Table 2. Summary of experimental results-single-baseline analysis.

	Baseline Mean (ms)	Treatment Mean(ms)	*p*
Subject 1			
Voice Onset - Word	N/A		
Voice Onset - Sentence	110.6	113.4	0.85
Vowel Duration - Word	412.6	398.2	0.31
Vowel Duration - Sentence	363.4	338.3	0.07
Sentence Duration	4509.3	3717.4	0.005
Subject 2			
Voice Onset - Word	55.7	92.0	0.008
Voice Onset - Sentence	49.0	63.1	0.003
Vowel Duration - Word	218.7	271.3	0.007
Vowel Duration - Sentence	175.2	197.7	0.04
Sentence Duration	1390.0	1678.4	0.008
Subject 3			
Voice Onset - Word	N/A		
Voice Onset - Sentence	57.0	93.5	0.01
Vowel Duration - Word	456.0	379.1	0.03
Vowel Duration - Sentence	344.8	290.6	0.02
Sentence Duration	3218.8	2752.2	0.02

Note: N/A = data not amendable to analysis;
Statistical significance indicated by $p<0.05$

was significant, all dependent measures were significant when baseline was compared to the three training phases combined. This result also supports a generalized training effect.

Some carryover of improved speech skills into daily activities was noted for Subjects 1 and 3 during the study. Subject 1 continued to demonstrate some carryover six months after the completion of the study. Results of a speech reassessment completed six months after the study revealed that the 99% intelligibility level had been maintained. Speech rate, however, decreased from 73 wpm to 60 wpm (pretraining = 44 wpm). Sixteen months after the study, speech intelligibility decreased to 76% (pretraining level = 78%), suggesting that spontaneous recovery was not a major factor in the observed changes in speech intelligibility and rate. Gains made during the three months of computer-based speech training were maintained for at least 6 months without further therapy. This result suggests that gains in speech rate and intelligibility achieved with computer-based speech training demonstrate carryover into the home and school environment.

The training effects observed in the three subjects generally support the value of SpeechViewer and the Stepping Stones Game for speech therapy with dysarthric patients. Additional studies of this type are needed to determine those procedures that are most effective for individuals at various ages who present different neurologic conditions and levels of speech performance. Speech acoustic measures were found to provide sensitive indicators of training effects, but associated analysis procedures might be greatly refined in future work by using smaller more selective speech samples. This would make it practical for acoustic analysis of training effects to become a routine component of speech therapy with dysarthric speakers.

Acknowledgments

This research was supported by The Ontario Ministry of Colleges and Universities (Grant #T08-010) and IBM Canada Ltd. The authors gratefully acknowledge Catherine McCann and Reinhard Schuller for their assistance in the data analysis, and the support of Mr. R. Mighton (IBM Canada Ltd.) and Mr. J. McTyre, Ms. L. Boyer, Mr. J. Roberts, Mr. W. Nawrocki (IBM; Boca Raton), and the administrative support of Ms. R. Gannon, Dr. S. Naumann, and Dr. M. Milner (HMRC).

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Appendix A

Acoustic Speech Sample

Name______________________________

Date______________________________

Tape______________________________

Counter Numbers______________________

Tape Sample # ______________________

Session #___________________________

Single Words

Pete	had
suit	tie
Kathy	shed
keep	cat
who	took
pie	pot
Tod	head
she	saw
two	trees

Sentences

Pete had a suit and tie.
Kathy should keep her cat.
Who took the pie and soda?
Tod should buy the pot.
She saw the two trees.