Changes in Speech Production Associated With Alphabet Supplementation

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Purpose: This study examined the effect of alphabet supplementation (AS) on temporal and spectral features of speech production in individuals with cerebral palsy and dysarthria.

Method: Twelve speakers with dysarthria contributed speech samples using habitual speech and while using AS. One hundred twenty listeners orthographically transcribed speech samples. Differences between habitual and AS speech were examined for intelligibility, rate, word duration, vowel duration, pause duration, pause frequency, vowel space, and first and second formant frequency (F1 and F2) values for corner vowels.

Results: Descriptive results showed that intelligibility was higher, rate of speech was slower, and pause duration and pause frequency were greater for AS than for habitual speech. Inferential statistics showed that vowel duration, word duration, and vowel space increased significantly for AS. Vowel space did not differ for male and female speakers; however, there was an interaction between sex and speaking condition. Changes in vowel space were accomplished by reductions in F2 for /u/. Vowel space accounted for more variability in intelligibility than rate for AS; the opposite was true for habitual speech.

Conclusion: AS is associated with temporal and spectral changes in speech production. Spectral changes associated with corner vowels appear to be more important than temporal changes.

KEY WORDS: intelligibility, speech acoustics, intervention, dysarthria, cerebral palsy

A*lphabet supplementation (AS)* is an intervention strategy used for enhancing the intelligibility of natural speech through provision of supplemental augmentative cues. When speakers implement AS, they use an alphabet board to indicate the first letter of constituent words of their message while saying each word at the same time. Consequently, each spoken word is associated temporally with a pointing gesture that ultimately yields meaningful linguistic (graphemic) information. Studies indicate that AS shows promise for improving speech intelligibility in individuals with dysarthria (Hanson, Yorkston, & Beukelman, 2004). Research suggests that alphabet cues improve intelligibility by an average of approximately 25% (range = 5%–69%) (Beukelman & Yorkston, 1977; Beukelman, Fager, Ullman, Hanson, & Logemann, 2002; Crow & Enderby, 1989; Hustad & Beukelman, 2001). Studies have included speakers varying in etiology of dysarthria, type of dysarthria, and severity of involvement. Generally, results indicate that speakers with more severe dysarthria tend to show greater benefit from AS than less severely involved speakers (Hanson et al., 2004).

There are several underlying reasons for intelligibility gains associated with AS. Perhaps most obvious is the linguistic information provided by the cues. Studies in which alphabet cues were digitally superimposed on predictable sentences produced using habitual speech have shown that first letter information has a significant effect on intelligibility (Beliveau, Hodge, & Hagler, 1995; Hustad, 2007; Hustad & Beukelman, 2001). In a recent study, Hustad (2007) examined the independent and joint influences of alphabet cues and semantic predictability on intelligibility of speakers with dysarthria. Results showed that alphabet cues increased intelligibility of semantically anomalous sentences by approximately 10% for speakers with dysarthria, demonstrating that the cues alone make an independent contribution to intelligibility gains. The same study also found that alphabet cues accounted for the greatest portion of variance in intelligibility gain scores (25%), followed by the joint influence of semantic predictability and alphabet cues (19%), and by semantic predictability alone (7.5%). Clearly, alphabet cues provide important information that helps listeners resolve lexical ambiguity.

Another means by which AS affects intelligibility is through alterations in production features of speech. Few studies have examined the exact nature of production changes associated with AS. However, changes in temporal features of speech, resulting in reduced rate, have been consistently documented when speakers implement the strategy (Beukelman et al., 2002; Hustad & Garcia, 2005; Hustad, Jones, & Daily, 2003b). Furthermore, there is evidence that changes in rate alone, even when listeners cannot see the alphabet cues, result in increased intelligibility when speakers implement AS (Beukelman & Yorkston, 1977; Crow & Enderby, 1989; Hustad & Garcia, 2005). Preliminary work exploring the nature of temporal changes associated with AS has suggested that speakers use longer and more frequently occurring interword pauses (Hustad & Garcia, 2005; Hustad et al., 2003b) and a slower rate of articulation (Hustad & Garcia, 2005) when they implement AS. Reduced rate has also been associated with increased intelligibility in other behavioral studies not involving AS (Hustad & Sassano, 2002; Pilon, McIntosh, & Thaut, 1998; Yorkston, Beukelman, & Traynor, 1990). However, the means by which rate reduction is accomplished seem to differ in important ways between AS and other rate reduction strategies. See Yorkston, Hakel, Beukelman, and Fager (2007) for a systematic review of the effects of rate reduction techniques in speakers with dysarthria.

Other studies have examined the effects of gestures on temporal features of speech. Studies examining iconic hand gestures produced concurrently with speech by individuals with dysarthria have shown that some individuals may reduce their speaking rate (Hustad & Garcia, 2005) and/or change the phrasing of their speech so that content linked to the gestures is chunked together (Garcia & Cobb, 2000; Garcia, Cannito, & Dagenais, 2000). Similar findings have also been reported when simultaneous communication (i.e., using a formal sign system while at the same time producing speech) is implemented by normal-hearing speakers (Schiavetti, Whitehead, & Metz, 2004). Not surprisingly, the co-production of speech and some type of manual movement or gesture seems to alter temporal characteristics of the acoustic signal.

Although there is a significant body of literature documenting spectral characteristics of dysarthric speech (Kent, Weismer, Kent, Vorperian, & Duffy, 1999), spectral changes associated with AS have not been studied. In general, research on spectral aspects of dysarthric speech has shown that vowel space is reduced relative to nondisordered speech (Turner, Tjaden, & Weismer, 1995; Weismer, Jeng, Laures, & Kent, 2001; Weismer, Laures, Jeng, & Kent, 2000). Furthermore, research has demonstrated a relationship between speech intelligibility and vowel space in adult speakers with dysarthria, such that larger vowel spaces are associated with better speech intelligibility (Liu, Tsao, & Kuhl, 2005; Turner et al., 1995; Weismer et al., 2001). In fact, studies have revealed that vowel space can account for nearly 50% of the variability in intelligibility scores. Because this finding has been replicated several times, including with speakers of different languages, it appears to be robust.

One source of information regarding potential spectral changes in speech associated with AS comes from the rate manipulation literature. Studies of rate-manipulated speech have examined individuals without speech disorders (Bradlow, Torretta, & Pisoni, 1996; Fourakis, 1991; Tsao, Weismer, & Iqbal, 2006) as well as individuals with dysarthria of varying etiology (Tjaden & Wilding, 2004; Turner et al., 1995; Weismer et al., 2000). Results across populations suggest that at slower speech rates, vowel space tends to be larger. For speakers with dysarthria, the expanded vowel space that occurs when speech rate is reduced more closely approximates vowel spaces and, by inference, vocal tract configurations, observed in individuals without speech disorders. Therefore, expanded vowel space may be one consequence when speakers implement AS.

Other studies have examined spectral changes in vowels associated with concurrent production of manual gesture/sign language and speech; findings have been somewhat contradictory. For example, one study demonstrated that linguistically meaningful hand gestures, produced concurrently with a spoken word of the same meaning, resulted in increased average values for F2 relative to the same word produced without the corresponding gesture and the same word produced with a meaningless gesture (Bernardis & Gentilucci, 2006). From these findings, the authors suggested that gestures which carry meaning may influence F2 values. However, findings that are somewhat different have been reported in the literature examining the impact of simultaneous communication on vowels. Specifically, results of a study examining monosyllabic words produced in carrier phrases showed that F1 and F2 values did not differ between habitual speech and speech produced while implementing simultaneous communication (Schiavetti, Metz, et al., 2004). One important variable that may account for the discrepancy in spectral findings relates to experience. Participants in the study by Schiavetti, Metz, and colleagues were all experienced in the use of simultaneous communication (more than 15 years of experience each), whereas participants in the study by Bernardis and Gentilucci did not have special characteristics. It is also important to note that studies examining co-production of gestures/signs and speech employed individuals with normal motor control abilities. Findings may be different for speakers with speech-motor and upper-extremity involvement.

The focus of the present study was on characterizing speech production changes associated with speaker-implemented AS and examining the extent to which findings were similar to those observed in the dysarthria rate manipulation literature and the gestures/signing literature. The following specific questions were addressed:

1. What is the effect of speaker-implemented AS on temporal features of speech? Measures of interest were overall speech rate, word duration, pause duration, pause frequency, and duration of corner vowels. Based on previous research on AS and on simultaneous communication, we expected that speech rate would be significantly reduced when speakers implemented AS and that word duration, pause duration, pause frequency, and corner vowel duration would all be significantly increased when speakers implemented AS, relative to habitual speech.
2. What is the effect of speaker-implemented AS on spectral features of speech? Measures of interest were vowel space, and F1 and F2 values for the four corner vowels (/i/, /ɑ/, /u/, /æ/). In addition, because studies have shown that vowel space is influenced by sex (Hazan & Markham, 2004; Tsao et al., 2006), we expected that female speakers would tend to have larger vowel spaces in each condition than male speakers but that both groups of speakers would show larger vowel spaces in the AS condition than in the habitual speech condition following predictions from the rate reduction literature. For each corner vowel, differences between F1 for the AS condition and habitual condition and differences in F2 for the AS and habitual condition were of interest to describe the specific means by which vowel space changed between speaking conditions. Following the gesture literature, we expected that F2 values would be higher for the AS condition than for the habitual speech condition.
3. Do temporal or spectral measures make a greater contribution to explaining variability in intelligibility scores for the habitual and AS speaking conditions? Because vowel space has been shown to account for a great deal of variability in intelligibility scores for speakers with dysarthria (Liu et al., 2005; Turner et al., 1995), we expected that vowel space would account for the greatest amount of variance in the habitual and AS speaking conditions.

Method

Participants: Speakers and Listeners

Twelve individuals with dysarthria secondary to cerebral palsy participated as speakers in this study. Speakers produced speech samples using habitual speech; they also produced the same speech samples while using AS. Speaker demographics, including type of dysarthria and prominent speech characteristics, are presented in Table 1. Inclusion criteria required that each speaker (a) be able to produce connected speech consisting of at least eight consecutive words, (b) be a native speaker of American English, (c) have functional literacy skills at or above the 6th grade level, (d) have corrected or uncorrected vision within normal limits per self-report, (e) have hearing within normal limits per self-report, and (f) be able to select letters accurately from an alphabet board using either the right or left hand. Participants were 5 men and 7 women. The mean age of speakers was 45.25 years (*SD* = 15.80).

One hundred twenty adults participated as listeners in this study. Ten different listeners were randomly assigned to each of the 12 speakers. Each listener viewed the same speaker in each of the two experimental conditions (habitual speech and AS). Inclusion criteria required that each listener (a) pass a pure-tone hearing screening at 25 dB SPL for 250 Hz, 500 Hz, 1 kHz, 4 kHz, and 6 kHz bilaterally; (b) be between 18 and 45 years of age; (c) have no more than incidental experience listening to or communicating with persons having communication disorders; (d) be a native speaker of American English; and (e) have no identified language, learning, or cognitive disabilities per self-report. Participants were 38 males and 82 females. The mean age of listeners was 20.32 years (*SD* = 3.52).

Materials and Procedures

Acquisition of Speech Samples

Speakers produced 60 different stimulus sentences in each of two speaking conditions (habitual speech and

Table 1. Characteristics of participants with dysarthria.

Speaker	Age	Sex	Dysarthria type	Perceptual features of speech	Intelligibility (%)	Education	Employment status
A	27	F	Spastic	• Imprecise articulation • Short phrases • Hypernasality • Monopitch	3	Completed high school	Unemployed
B	30	F	Mixed spastic-hyperkinetic	• Imprecise articulation • Short phrases • Hypernasality • Monopitch	5	Completed high school	Clerical assistant
C	41	M	Spastic	• Imprecise articulation • Short phrases • Hypernasality • Monopitch	11	Completed high school	Clerical assistant
D	56	M	Mixed spastic-hyperkinetic	• Imprecise articulation • Short phrases • Strained-strangled vocal quality • Hypernasality • Monopitch	14	Completed high school	Public relations
E	57	M	Spastic	• Imprecise articulation • Hoarse vocal quality • Hypernasality • Monopitch	35	No formal education	Public speaker
F	46	M	Spastic	• Imprecise articulation • Short phrases • Hypernasality • Harsh vocal quality	50	Bachelor of science degree	Service coordinator
G	50	F	Spastic	• Imprecise articulation • Short phrases • Harsh vocal quality • Monopitch	51	Completed 11th grade	Clerical assistant
H	43	F	Spastic	• Imprecise articulation • Monopitch	67	Completed high school	Unemployed
I	76	F	Spastic	• Imprecise articulation • Short phrases • Harsh vocal quality • Monopitch	68	Completed high school	Retired
J	24	F	Spastic	• Imprecise articulation • Hypernasality	73	Currently attending college	Student
K	31	F	Spastic	• Imprecise articulation	88	Associate degree	Secretary
L	62	M	Hypokinetic	• Imprecise articulation • Breathy vocal quality • Rapid rate of speech	89	Completed 6th grade	Clerical assistant

Note. Perceptual features of speech and dysarthria type were determined by a certified speech-language pathologist. Intelligibility scores were obtained from the Sentence Intelligibility Test.

AS), for a total of 120 sentences. Stimulus sentences were developed for research purposes by Boothroyd and Nittrouer (1988) and have been used in previous studies of intelligibility (see Nittrouer & Boothroyd, 1990). One key feature of these sentences is that they vary in semantic predictability, with 20 sentences having high predictability, 20 having low predictability, and 40 being unpredictable (only 20 of the unpredictable sentences were used in the present study). All stimulus sentences were declarative or imperative and comprised four words. Although phonetic characteristics of the individual words making up the sentences varied, all words were monosyllabic (e.g., "Tough guys sound mean."; "Warm sun feels good."; "Fresh bread smells great."). For the present study, productions of the same 16 stimulus sentences from each of the two speaking conditions were analyzed and directly compared. Individual sentences were selected based upon the presence of corner vowels.

Prior to recording the stimulus sentences, speakers were instructed in the use of AS, following procedures from previous studies (Hustad, Auker, Natale, & Carlson, 2003a; Hustad et al., 2003b). Instruction involved a verbal description of AS, including an explanation of the purpose of AS, and experimenter modeling of AS. Speakers then practiced using AS on a set of rehearsal sentences until they were able to use it comfortably and accurately. Correct implementation of AS required speakers to point to the first letter of each word while speaking the word. Following previous studies (Hustad et al., 2003a, 2003b), the timing of letter selection and speech production was controlled so that speakers selected the letter and simultaneously produced the target word or selected the letter and then produced the target word immediately afterward. All 12 speakers had good success with learning AS, and all were able to implement AS with little difficulty while producing the experimental speech stimuli. Learning time, prior to recording experimental speech stimuli, was less than 15 min per speaker.

For the habitual condition, speakers were instructed to speak naturally, as they would in typical communication situations. They were asked to produce each stimulus sentence following the experimenter's verbal model. An orthographic display of the stimulus sentences was also presented on a laptop computer for both the habitual and AS speaking conditions.

Recordings of speakers were made in a sound-attenuating suite using professional-quality digital video (Model GL-2 camcorder, Canon, Lake Success, NY) and audio recording equipment (Model PMD 670 recorder, Marantz, Mahwah, NJ; Model Isomax E6 head-mounted microphone, Countryman Associates, Menlo Park, CA). Positioning of the microphone was constant for each speaker, approximately 4–5 cm from the right side of each speaker's lips. Audio samples were recorded at a 44.1-Hz sampling rate (16-bit quantization). Speakers were seated in front of a neutral blue background for all recordings, and the laptop computer was positioned directly in front of each speaker and out of the camera's view. Video recordings focused on the speaker's upper body so that a lap-mounted communication board and the speaker's facial features were clearly visible. During recording, speakers were asked to repeat any sentence in which they (a) selected an inappropriate first letter, (b) spoke the word before indicating the first letter, or (c) did not produce all constituent words of the stimulus sentence.

Acquisition of Intelligibility Data

Preparing audio and video files for playback. Digital audio and video recordings of each speaker were transferred to a personal computer. Video recordings were edited using Adobe Premiere Pro. Audio recordings were edited using Sony Sound Forge 7.0. Editing involved separating digital recordings of each stimulus sentence into individual files. To ensure that the maximum loudness level of the audio recordings was constant across speakers and sentences, waveforms for individual sentences were peak-amplitude normalized. Any extraneous productions, aside from the stimulus sentences, were removed from the audio files.

Because videotapes were filmed from directly in front of each speaker, it was difficult to see individual letters to which speakers pointed on the videotape. Thus, videotapes were digitally enhanced (following Beukelman et al., 2002; Hanson & Beukelman, 2006; Hustad & Beukelman, 2001; Hustad et al., 2003a, 2003b) so that letters were clearly visible, as they might be if a listener was sitting next to the speaker. To do this, the first letter of each word was represented in a box to the right of the speaker's face on each video file. The onset of individual graphemes corresponded to the physical pointing gesture of the speaker and was displayed for the duration of the target word, as indicated by visual inspection of the speech waveform.

Data collection from listeners. Listeners completed two experimental tasks, one in which they viewed a single speaker producing stimulus sentences using habitual speech, and one in which they viewed the same speaker producing different sentences using AS. Listeners viewed recordings of speakers individually in a sound-attenuating room.

During the experiment, listeners were seated in front of a 19-in. (48.26-cm) flat-panel computer screen with a keyboard placed directly in front of them. An external speaker was connected to the computer and situated adjacent to the computer screen. The peak audio output level was calibrated to approximately 75 dB SPL from where listeners were seated and was checked periodically to ensure that all listeners heard stimuli at the same output level.

Speech stimuli were delivered via an in-house computer program that presented sentences and stored typed orthographic transcriptions. Listeners were allowed to view each sentence up to three times, at their discretion. To offset the potential impact of an order effect on results, the presentation sequence of the two experimental conditions (habitual speech and AS speech) was counterbalanced. In addition, for each listener, sentences were randomly assigned to each of the two conditions, so that different sentences were presented in each condition. The order of presentation of stimulus sentences in each condition was also randomized; thus, no two listeners heard the stimulus sentences in the same order.

Listeners were instructed that they would complete two tasks, one where a person with a speech impairment produced a series of sentences using "regular" speech, and one where the same person produced a different series of sentences using AS. Listeners were told that the purpose of the study was to determine whether AS helped people, like themselves, understand the speaker better. Listeners were instructed that speakers would be producing real words and to take their best guess if they were unsure as to what the speaker said. Listeners were provided with instructions on how to use the in-house software to advance through the experiment. In addition, they viewed two sample sentences to familiarize themselves with each task.

Analysis of Data: Speech Acoustics and Intelligibility

Intelligibility. Orthographic transcriptions of speakers with dysarthria were scored using the in-house computer program. The program automatically tallied the number of transcribed words that were an exact phonemic match to the stimuli produced by the speakers with dysarthria. Misspellings and homonyms were accepted as correct, as long as all phonemes in the transcribed words matched the target words. The number of words identified correctly across all 10 listeners for each speaker on the 16 stimulus sentences used in the acoustic analyses was summed and divided by the number of words possible for each experimental condition. The two resulting intelligibility scores (habitual speech and AS speech) for each speaker were used for intelligibility analyses.

Speech acoustics. Temporal and spectral acoustic measures were obtained from the digital speech samples using a wideband spectrographic display in TF 32 (computer software; Milenkovic, 2002), following established measurement criteria (Kent & Read, 2001; Kent et al., 1999; Klatt, 1976; Turner et al., 1995; Weismer et al., 2000). For each of the 16 stimulus sentences, the following measures were made for each speaker and speaking condition.

Duration of individual words within each utterance was determined by measuring the time between the onset and the offset of audible or visible (on the waveform and spectrogram display) acoustic energy associated with production of words comprising stimulus sentences.

Duration of the phonemes /i/, /æ/, /a/, and /u/ was determined by measuring the interval between the first and last glottal pulse where both F1 and F2 were visible on the spectrogram. Words containing corner vowels that were not immediately adjacent to nasals, liquids, or glides were selected for analysis; however, it was not possible to obtain enough analysis tokens for the vowel /u/ without including two tokens that were adjacent to a nasal (*new*) and one token that was adjacent to a liquid (*blue*). In addition, it was not possible to obtain enough analysis tokens for the vowel /ɑ/ without including two tokens that were adjacent to a glide (*rock*), and two tokens that were adjacent to a nasal (*on*). In these instances, acoustic cues such as abrupt increases in intensity and abrupt decreases in F2 were used to identify vowel offsets and onsets (see Tjaden, Rivera, Wilding, & Turner, 2005). Because the same stimulus words were examined in both speaking conditions and the differences between conditions for each speaker were of primary interest, the inclusion of some analysis tokens that were not ideal did not impact our ability to address the experimental questions.

Duration of interword pauses within each utterance was determined by measuring the time between the onset and offset of any audible or visible (on the waveform and spectrogram display) interval between words where no acoustic energy was present. There was no minimum-duration criterion for interword pauses; all visible pauses between words were measured.

Duration of each utterance was determined by adding word-duration and pause-duration values for each utterance.

F1 and F2 frequencies, for the phonemes /i/, /æ/, /a/, and /u/ were determined using both wideband spectrographic and spectrum displays from a 30 ms window at the temporal midpoint of each vowel. Spectrogram analysis bandwidth was adjusted for each speaker based on the speaker's fundamental frequency (F0; as determined by the TF32 average F0 algorithm). A bandwidth that was approximately double the speaker's F0 was used for analysis. Linear predictive coding was used to generate formant tracks, which were hand corrected to reflect the spectral midpoint of each vowel, as necessary, based on visual inspection of the spectrogram.

For temporal measures, all spoken productions of each target sentence were included in the analyses. For spectral measures, five tokens of /ɑ/, /æ/, and /u/, and 7 tokens of /i/, were averaged within individual speakers and speaking conditions. Computations based on spectral data were made from averages across tokens for individual vowels, speakers, and speaking conditions.

The following formulae were used to obtain the dependent variables for each speaker and speaking condition subjected to statistical analyses: (a) speech rate = (total number of words produced)/(total duration of utterances), (b) average word duration = (duration of all words)/(total number of words produced), (c) average corner vowel duration = (duration of each corner vowel)/(total number of each corner vowel produced), (d) average interword pause duration = (duration of all pauses)/(total number of pauses produced), (e) average pause frequency = (total number of pauses)/(total number of utterances), and (f) vowel quadrilateral area = ½(F1/i/ × F2/u/ – F1/u/ × F2/i/) + ½(F1/u/ × F2/ɑ/ – F1/ɑ/ × F2/u/) + ½(F1/ɑ/ × F2/æ/ – F1/æ/ × F2/ɑ/) + ½(F1/æ/ × F2/i/ – F1/i/ × F2/æ/) (Johnson, Flemming, & Wright, 2004).

Inter- and intrajudge reliability was obtained for all acoustic measures. Intrajudge reliability involved having the same judge make a second set of acoustic measures on 2 of 16 sentences for each of the 12 speakers. Pearson product–moment coefficients for the first and second set of measures ranged between .951 and .999. Absolute differences between measures were 13.43 ms for pause duration, 26.51 ms for word duration, 17.67 Hz for F1, and 27.00 Hz for F2. Interjudge reliability involved having a second judge, who was trained in acoustic analysis methods, evaluate 2 of 16 sentences for each of the 12 speakers. Pearson product–moment correlation coefficients for the measurements made by the first and second raters ranged from .994 to .999. Absolute differences between measures were 13.35 ms for pause duration, 12.32 ms for word duration, 8.45 Hz for F1, and 20.11 Hz for F2. All reliability measures fell within an acceptable range following Kent et al. (1999).

Experimental Design and Analysis

This study employed a 1 × 2 repeated measures design to examine the difference between speaking conditions (habitual speech and AS speech) for six of the seven dependent measures: intelligibility, word duration, pause duration, pause frequency, vowel duration, and speech rate. For the seventh dependent measure, vowel space, a 2 × 2 split plot design was employed to examine the effects of sex and speaking condition.

For the intelligibility, pause duration, pause frequency, and speech rate variables, only descriptive statistics are presented, as statistically significant effects of AS have been well documented in the literature. Formal inferential statistics were performed on three of the variables: word duration, vowel duration, and vowel space. Separate analyses of variance (ANOVAs) were performed for these three variables. Statistics with an alpha level less than .05 were considered significant. In addition, for vowel space data, follow-up tests were performed to explore F1 and F2 differences between conditions for each of the four corner vowels. For these tests, an alpha level of .05 was assigned to each family of tests (F1 differences and F2 differences) and was partitioned across contrasts using the Bonferroni procedure (4/.05). Consequently, a probability value of .0125 or less was necessary for any follow-up contrast to be considered significant.

Finally, two stepwise regression analyses were performed to determine whether vowel space or speech rate made a greater contribution to intelligibility in the habitual speech condition and in the AS condition. Statistics with probability values of .05 or less were considered significant.

Results

This study focused on describing underlying speech production changes associated with intelligibility gains that occurred when speakers with dysarthria implemented AS. Therefore, the first set of analyses quantified the intelligibility gains observed with implementation of AS. Descriptive results, shown in Figure 1, demonstrated that intelligibility increased for each of the 12 speakers when AS was implemented. The mean gain across all speakers was 14.81% (*SD* = 7.69); gains for individual speakers ranged from 3.34% to 28.47%.

Temporal Aspects of Speech

Five different temporal variables were examined: speech rate, word duration, corner vowel duration, pause duration, and pause frequency. Descriptive results for speech rate, shown in Figure 2, reveal that the average rate of speech (including all pauses) decreased for all 12 individual speakers when AS was implemented. The mean speech rate decrease across all speakers was 44.17 wpm (*SD* = 22.68); decreases for individual speakers ranged from 8.46 wpm to 84.29 wpm.

Descriptive results for word duration, provided in Table 2, showed that the average duration of individual words increased for 10 of 12 speakers when AS was implemented. The mean word duration increase across all

Figure 1. Mean percent of words identified correctly by speaker and speaking condition.

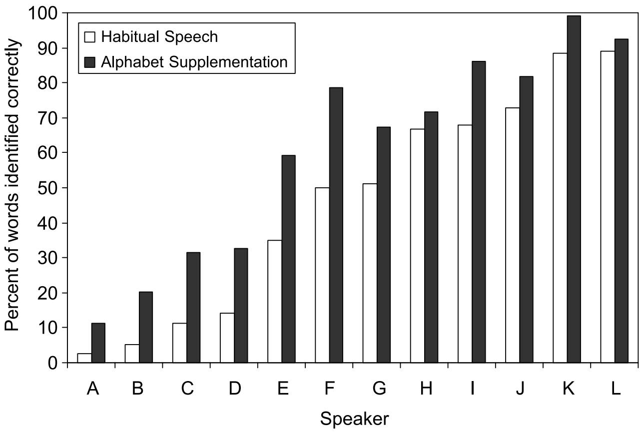
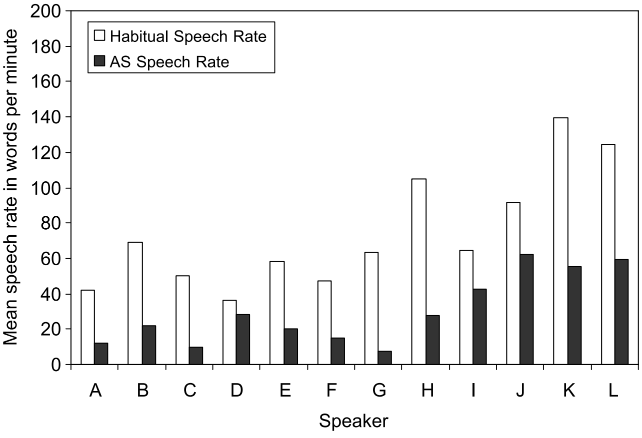


Figure 2. Mean speech rate (in words per minute) by speaker and speaking condition. Note that speech rate data are averaged across utterances for each speaker and reflect all pauses produced during each utterance. AS = alphabet supplementation.



speakers was 132.33 ms (*SD* = 115.28); changes in word duration for individual speakers ranged from –4.60 ms to 344.51 ms. Inferential statistics indicated that word duration was significantly longer when speakers implemented AS, $F(1, 11) = 15.81, p < .002$.

Descriptive results for vowel duration, shown in Table 3, suggested that the mean duration of the vowel /i/ increased for 8 of 12 individual speakers when AS was implemented. The mean duration increase for /i/ across all speakers was 28.84 ms (*SD* = 62.67); however, inferential statistics showed that this difference was not significant, $F(1, 11) = 2.54, p = .139$. For the vowel /u/, descriptive results showed that the mean duration increased for 9 of 12 speakers when AS was implemented. The mean duration increase for /u/ was 66.47 ms (*SD* = 92.89); inferential statistics showed that this difference was significant, $F(1, 11) = 6.14, p = .031$. For the vowel /ɑ/, descriptive results showed that the mean duration increased for 11 of 12 speakers when AS was implemented. The mean duration increase for /ɑ/ was 61.54 ms (*SD* = 57.13); this difference was significant, $F(1, 11) = 13.92, p = .003$. Finally, for the vowel /æ/, descriptive results showed that the mean duration increased for 9 of 12 speakers when AS was implemented. The mean duration increase for /æ/ was 34.52 ms (*SD* = 51.49); this difference was significant, $F(1, 11) = 5.39, p = .04$.

Descriptive results for pause duration, shown in Table 2, demonstrated that the average duration of individual pauses increased for all 12 individual speakers when AS was implemented. The mean pause duration increase across all speakers was 2,600.34 ms (*SD* = 2,572.27). Increases in pause duration for individual speakers ranged from 430.00 ms to 8,402.55 ms.

Descriptive results for pause frequency, shown in Table 2, demonstrated that the average frequency of individual pauses increased for all 12 individual speakers when AS was implemented. The mean pause frequency increase across all speakers was 1.05 pauses (*SD* = 0.66); increases for individual speakers ranged from 1.94 pauses to 0.06 pauses per utterance.

Spectral Aspects of Speech

Descriptive results for vowel space, shown in Figure 3, indicate that the average vowel space increased for 10 of 12 individual speakers when AS was implemented (one speaker showed no change in vowel space; one speaker showed a decrease in vowel space). The mean vowel space increase across all speakers was 39470.60 Hz^2 (*SD* = 36579.85); changes for individual speakers ranged from

Table 2. Word duration, pause duration, and pause frequency by individual speaker for habitual and alphabet supplementation conditions.

	Habitual speech			Alphabet supplementation		
Speaker	Average word duration (ms)	Average pause duration (ms)	Average pause frequency (from a possible 3)	Average word duration (ms)	Average pause duration (ms)	Average pause frequency (from a possible 3)
A	849	787	3	1,178	5,089	3
B	457	558	3	537	2,972	3
C	662	883	2	657	7,136	3
D	1,329	494	3	1,463	924	3
E	953	222	1	950	2,732	3
F	768	1,060	2	966	4,044	3
G	782	397	2	1,126	8,799	3
H	500	214	1	605	2,062	3
I	851	149	2	908	678	3
J	626	72	1	657	502	2
K	404	61	1	582	676	3
L	371	177	1	510	663	3

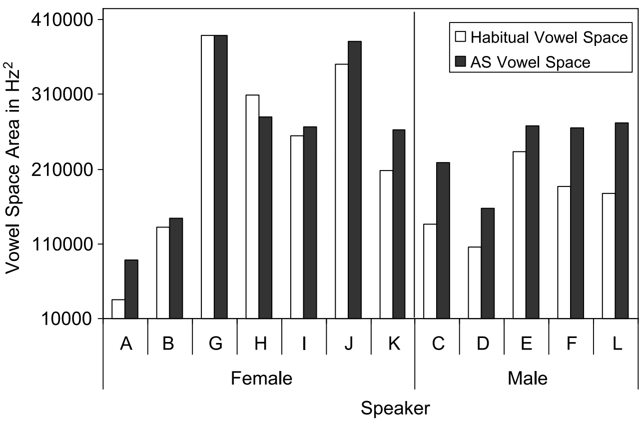
Table 3. Mean change in vowel duration (in ms) by individual speaker between alphabet supplementation and habitual conditions.

	Differences between alphabet-supplemented speech and habitual speech			
Speaker	**/i/ duration change**	**/u/ duration change**	**/ɑ/ duration change**	**/æ/ duration change**
A	–24	74	26	–16
B	40	86	52	24
C	–62	–81	–23	–43
D	–36	196	23	122
E	59	66	17	46
F	72	–34	60	0
G	149	203	160	107
H	18	64	98	33
I	–51	117	155	38
J	32	–83	5	–28
K	71	114	91	80
L	77	74	76	51

–29080.13 Hz^2 to 94915.14 Hz^2. Inferential statistics indicated that vowel space was significantly larger when speakers implemented AS, $F(1, 10) = 28.57$, $p < .001$. The main effect of sex was not significant, $F(1, 10) = .71$, $p = .420$, and the Sex × Speaking Condition interaction was significant, $F(1, 10) = 9.01$, $p = .013$, indicating that vowel space changes were different for male and female speakers.

To determine the nature of the articulatory changes that were responsible for the increase in vowel space, a series of *t* tests was performed examining differences in F1 between the two speaking conditions and differences in F2 between the two speaking conditions for each corner vowel. Results showed that F1 differences between the AS and habitual speaking conditions were not significant for any of the corner vowels: /i/, $t(11) = –0.017$, $p = .987$; /u/, $t(11) = 1.752$, $p = .108$; /æ/, $t(11) = 0.64$, $p = .534$; /ɑ/, $t(11) = –0.62$, $p = .549$. However, results showed that for F2, the difference was significant for /u/, $t(11) = 3.33$, $p = .007$, but not for the other corner vowels: /i/, $t(11) = –1.01$, $p = .334$; /æ/, $t(11) = –1.86$, $p = .089$; /ɑ/, $t(11) = 2.10$, $p = .059$. For /u/, F2 was 71.13 Hz lower for the AS condition than for the habitual condition. Figures 4 and 5 show average vowel quadrilaterals in each speaking condition for men and women, respectively.

Figure 3. Mean vowel space (in Hz^2) by speaker and speaking condition.



Contributors to Speech Intelligibility

Two analyses were performed in which speech rate and vowel space were regressed onto intelligibility for the

Figure 4. Vowel quadrilaterals for male speakers ($N = 5$) by speaking condition. The red symbols are the mean first and second formant frequency (F1 and F2, respectively) values for the habitual speech condition; the dashed line connecting the red symbols shows the average vowel quadrilateral across the male speakers for the habitual speech condition. The green symbols are the mean F1 and F2 values for the alphabet supplementation condition; the solid line connecting the green symbols shows the average vowel quadrilateral across the male speakers for the alphabet supplementation condition. AS = alphabet supplementation; Hab = habitual.

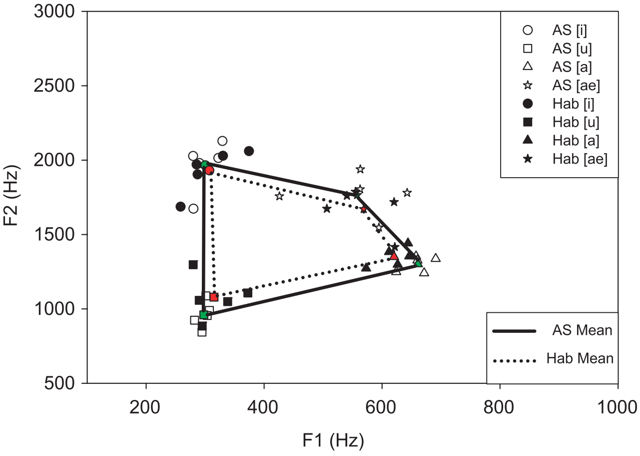
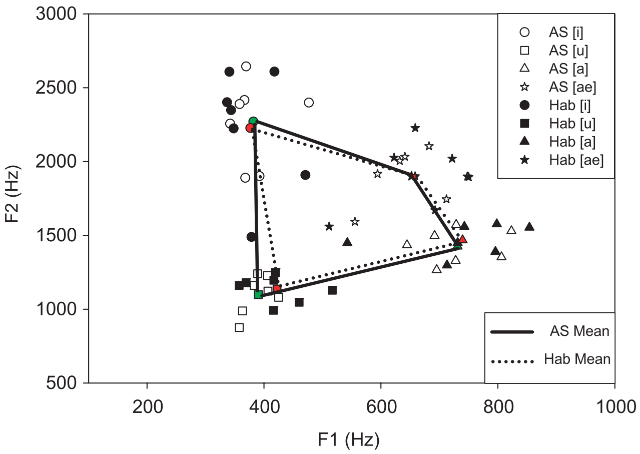


Figure 5. Vowel quadrilaterals for female speakers ($N = 7$) by speaking condition. The red symbols are the mean first and second formant frequency (F1 and F2, respectively) values for the habitual speech condition; the dashed line connecting the red symbols shows the average vowel quadrilateral across the female speakers for the habitual speech condition. The green symbols are the mean F1 and F2 values for the alphabet supplementation condition; the solid line connecting the green symbols shows the average vowel quadrilateral across the female speakers for the alphabet supplementation condition.



AS and habitual speech conditions. For the AS condition, vowel space made the greatest contribution to intelligibility, $R^2 = .56$, $F(1, 10) = 12.74$, $p < .005$, accounting for 56% of the variance. Speech rate also made a significant contribution to intelligibility, $\Delta R^2 = .20$, $\Delta F(1, 9) = 7.30$, $p < .024$, accounting for an additional 20% of the variance. In total, these variables accounted for 76% of the variance in intelligibility scores in the AS condition.

For the habitual condition, speech rate made the greatest contribution to intelligibility, $R^2 = .65$, $F(1, 10) = 18.68$, $p < .002$, accounting for 65% of the variance. Vowel space also made a significant contribution to intelligibility, $\Delta R^2 = .13$, $\Delta F(1, 9) = 5.21$, $p < .048$, accounting for an additional 13% of the variance. In total, these two variables accounted for 78% of the variance in intelligibility scores in the habitual condition.

Discussion

This study examined speech production changes associated with implementation of AS in speakers with dysarthria. Twelve speakers with dysarthria learned to use AS, and speech samples were recorded under two conditions for each speaker: (a) speech produced habitually and (b) speech produced when using AS. Speech samples were orthographically transcribed by 120 normal-hearing listeners. Speech samples were also subjected to detailed temporal and spectral acoustic analyses. Results showed that significant temporal and spectral changes occurred when speakers implemented AS and that production features explaining intelligibility were different for habitual speech than for speech produced with AS.

Speech Intelligibility

Results of the present study showed that intelligibility increased for all speakers when they implemented AS. Although the magnitude of this gain varied among speakers, the average absolute difference was approximately 15%, which was a proportional increase of 32% relative to habitual intelligibility. This finding is consistent with previous studies examining speaker-implemented AS (Beukelman & Yorkston, 1977; Beukelman et al., 2002; Crow & Enderby, 1989; Hustad & Garcia, 2005; Hustad et al., 2003b). Although most previous studies have examined speakers with moderately or severely reduced intelligibility, the present study demonstrates that speakers with mildly reduced intelligibility can also benefit from AS (see Figure 1, Speakers J, K, and L), albeit to a lesser extent than more involved speakers.

Temporal Aspects of Speech

Results of this study showed consistent changes in temporal aspects of speech when speakers implemented AS. The reduction in speech rate for AS across speakers was approximately 60% relative to habitual rate and was consistent with previous studies of AS, showing reductions between 50% and 80% relative to habitual rate (Beukelman et al., 2002; Hustad & Garcia, 2005; Hustad et al., 2003b). This overall rate change was accomplished in two ways. Word and vowel duration were increased by approximately 16% and 13% relative to habitual durations, respectively, when speakers implemented AS. In addition, pause duration and pause frequency were increased by approximately 86% and 36% relative to habitual values, respectively, when speakers implemented AS. It is particularly noteworthy that most speakers paused the maximum number of times possible between words when implementing AS. Descriptive findings suggest that pause duration and pause frequency were the primary means by which rate was reduced when speakers implemented AS and that word and phoneme duration increases were the secondary means. There are several potential consequences to temporal changes of this nature. First, observations made during acoustic analyses indicated that co-articulation tended to be minimized and word boundaries were clear and definitive, potentially reducing the demands of parsing the acoustic signal into lexical units by listeners. In addition, the increased pause frequency and duration likely afforded listeners extra processing time between words. Finally, reduced rate may have given speakers more time to achieve vocal tract configurations that more closely approximated those of nondysarthric individuals (Duffy, 2005). This speculation is supported by spectral findings discussed next.

Spectral Aspects of Speech

Results of the present study showed that vowel space increased, relative to habitual speech, when speakers implemented AS. Across speakers, vowel space was approximately 19% larger for AS than for habitual speech. This finding is consistent with other studies examining changes in vowel space associated with behavioral rate reduction in speakers with dysarthria (Turner et al., 1995).

One surprising result from the present study was that absolute vowel space sizes did not differ for male and female speakers. Descriptive data regarding average formant values across speakers suggest that female speakers consistently had higher F1 and F2 values than male speakers, as expected. However, individual speaker data (Figure 3) suggest that the nonsignificant overall difference in vowel space between male speakers and female speakers was likely due to Speakers A and B, both of whom were female, had very small vowel spaces, and had severe dysarthria. It is also interesting that the increase in vowel space associated with AS was significantly larger for male speakers than for female speakers. Vowel space increased by 40% for male speakers and 11% for female speakers. Thus, there was a 29% greater gain in vowel space for male speakers, on average, than for female speakers. Again, this finding is likely related to individual speaker characteristics (i.e., Speakers A and B). Additional studies are needed to further examine this question.

With regard to the means by which vowel space was increased when speakers implemented AS, results across speakers showed that the only significant contributor was lower F2 values for /u/, suggesting that speakers used greater tongue retraction and perhaps greater lip rounding in the AS condition for this vowel. However, there was marked variability in formant values for each of the vowels among speakers, as shown in Figures 4 and 5. The relatively small number of speakers combined with this variability may have obscured other potential effects. For example, although not statistically significant, descriptive findings revealed that at least some speakers, particularly males, had altered F2 values for /æ/ and /ɑ/ in the AS condition. This finding relates to the work of Bernardis and Gentilucci (2006), who found that F2 values changed when manual gestures were combined with production of words of the same meaning. It is noteworthy, however, that the direction of change in F2 differed in the present study—that is, F2 values decreased for both of the back vowels and increased for one of the front vowels, which served to move F2 in the more extreme and appropriate direction with regard to tongue retraction and advancement, respectively. Ultimately, this would likely serve the purpose of increasing distinctiveness of individual vowels. There are several possible reasons for the difference in findings between the present study and that of Bernardis and Gentilucci (2006). In the later study, only three word tokens were examined, one of which contained a corner vowel. Words were spoken by neurologically typical speakers who produced hand gestures while speaking. Consequently, it is difficult to generalize across studies; however, collectively this work suggests that co-production of words and meaningful hand gestures may result in notable changes in acoustic features of speech.

Contributors to Speech Intelligibility

In previous research, vowel space has been shown to account for a large amount of variance in intelligibility scores (Liu et al., 2005; Turner et al., 1995; Weismer et al., 2001). In the present study, we hypothesized that similar findings would also occur and that vowel space would make a larger contribution to intelligibility in both the habitual and AS speaking conditions than changes in speech rate. Findings were generally consistent with previous literature with regard to amount of variability in intelligibility scores accounted for by vowel space. In the habitual condition, our findings were slightly lower (38% of variance accounted for) than findings of previous studies. In the AS condition, our findings were slightly higher (56% of variance accounted for) than findings of previous studies. Perhaps most interesting was that the best predictor of intelligibility differed for the two speaking conditions. For the AS condition, vowel space accounted for more variance in intelligibility than speech rate, as predicted. However, in the habitual condition, speech rate accounted for more variance in intelligibility than vowel space. This was somewhat surprising given the magnitude of the relationship between vowel space and intelligibility for habitual speech. However, this finding highlights the powerful relationship between speech rate and intelligibility.

Limitations

As with any experimental research, there are several important limitations to the present study that reduce its generalizability. First, this study used only 5 men and 7 women with dysarthria. These individuals varied in their gross, fine, and speech motor control abilities; yet it is unlikely that they represented the range of individuals with cerebral palsy and dysarthria. Because the number of participants was small and there was considerable variability among participants, conclusions from this article should be regarded with caution. Although findings may not represent the definitive answer regarding speech production changes associated with AS, they do provide a starting point for future hypotheses regarding speech production changes associated with dysarthria interventions.

A small number of spectral variables were considered in the present study, and these were focused exclusively on corner vowels. Other candidate measures that may provide important information regarding speech production changes include spectral moments for fricative or stop bursts (Tjaden & Turner, 1997) and F2 slope to examine transitions between consonants and vowels (Kent, et al., 1989; Weismer & Martin, 1992). In addition, measures examining changes in F0 should be considered, as monopitch has been reported as a perceptual feature of speech produced with AS (Hustad & Weismer, 2007).

Speakers produced sentences in a recitation format for this study. As such, there may have been production differences between the "habitual speech" condition and true spontaneous habitual speech. In addition, stimulus sentences were short and consisted of monosyllabic words. Production features associated with this type of stimulus material may not reflect what happens when speakers produce sentences of different grammatical and lexical construction or sentences formulated by the speaker during communication interchanges. The study of production changes associated with implementation of AS in different contexts is necessary to fully understand the ways that AS affects speech.

Clinical Implications

Results of this study demonstrated that for the 12 speakers with dysarthria who participated in this study, AS resulted in changes in temporal and spectral aspects of speech production. Together with the linguistic information provided by the alphabet cues, production changes resulted in significant improvements in intelligibility. Because there was not a condition in this study where listeners only heard speech, without benefit of the visual alphabet cues, it is impossible to determine the independent contributions to intelligibility of linguistic information provided by alphabet cues and changes in production features of speech. However, temporal and spectral changes observed in this study were similar to those reported in the rate reduction literature (Turner et al., 1995) and were also generally consistent with findings from the gesture literature (Bernardis & Gentilucci, 2006). Additional study is needed to determine the independent effect of production changes on intelligibility; however, it is very likely that production changes alone are responsible for a portion of the intelligibility gain reported in the present study.

Clinicians should consider AS as an intervention strategy for speakers with dysarthria who have reduced intelligibility and who are able to use their hands to select letters on an alphabet board while simultaneously producing speech. The strategy was easily learned by all speakers who participated in this research and is a low-cost intervention with significant potential for increasing intelligibility. In addition to its compensatory usefulness, AS may also be a valuable strategy for teaching speakers to alter speech production behavior.

Acknowledgments

This research was funded by National Institute on Deafness and Other Communication Disorders Grant R03 DC005536. We thank Caitlin Dardis, Kelly McCourt, and Joy Taylor-Wade for assistance with data collection and data analysis. We also thank Gary Weismer for assistance with acoustic analyses and for feedback on sections of this article. Portions of these data were presented at the 2006 American Speech, Language, and Hearing Association Annual Convention in Miami, Florida.

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Received September 11, 2007

Accepted March 19, 2008

DOI: 10.1044/1092-4388(2008/07-0185)

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