Effects of Linguistic Cues and Stimulus Cohesion on Intelligibility of Severely Dysarthric Speech

Katherine C. Hustad
Department of Communication Disorders
The Pennsylvania State University
University Park

David R. Beukelman
Department of Special Education and Communication Disorders
University of Nebraska
Lincoln

This study examined the effects of supplemental cues on the intelligibility of unrelated sentences and related sentences (narratives) produced by 4 women with severe dysarthria secondary to cerebral palsy. Visual images containing alphabet, topic, combined (alphabet and topic together), and no cues were imposed in real time on audio speech samples and presented to 72 nondisabled listeners. Statistical results showed that cue conditions had similar effects on unrelated and on related sentence intelligibility. Combined cues resulted in higher intelligibility scores than any other cue condition, no cues resulted in lower intelligibility scores than any other cue condition, and alphabet cues yielded higher intelligibility scores than topic cues. Intelligibility of related and unrelated sentences differed only for alphabet cues where related sentences had greater intelligibility than unrelated sentences. Results are discussed relative to the quantity and type of cues.

KEY WORDS: intelligibility, speech perception, motor speech disorders, speech supplementation strategies, augmentative communication

Reduced speech intelligibility is a hallmark characteristic of most of the dysarthrias (Tikofsky & Tikofsky, 1964; Yorkston, Beukelman, & Bell, 1988). Speech intelligibility has been defined broadly as the accuracy with which an acoustic signal is conveyed by a speaker and recovered by a listener (Kent, Weismer, Kent, & Rosenbek, 1989; Yorkston & Beukelman, 1980; Yorkston, Beukelman, Strand, & Bell, 1999; Yorkston, Strand, & Kennedy, 1996). Listeners of speakers with reduced intelligibility that is due to dysarthria are often faced with the difficult task of deriving the speaker's intended meaning from a compromised acoustic-phonetic signal. Fortunately, variables in addition to the acoustic-phonetic signal itself contribute to a listener's ability to process dysarthric speech. Intelligibility is a fluctuating phenomenon that depends on a host of factors pertaining to both speaker and listener (Connolly, 1986; Hustad, Beukelman, & Yorkston, 1998; Kent, 1993). The focus of the present study is on manipulation of variables associated with the listener.

Two primary sources of information play a role in a listener's ability to disambiguate speech (Lindblom, 1990; Marslen-Wilson & Welsh, 1978; McClelland, 1991; Vogel & Miller, 1991). First, listeners have the intrinsic capability for inductive or bottom-up processing of the acoustic speech signal, parsing acoustic information into phonetic and linguistic units based on information present within the signal (Marslen-Wilson & Welsh, 1978). Second, listeners possess higher-level knowledge of the language that includes an understanding of and context-specific expectations for syntax, semantics, and pragmatics. This type of knowledge is deductive or top-down in nature (Marslen-Wilson & Welsh, 1978; Vogel & Miller, 1991) and enables listeners to take available information, which may be incomplete, and construct or infer a whole. The role of each source of information in speech processing by listeners has been a topic of considerable debate in the speech perception literature (Marslen-Wilson, 1987; McClelland, 1991; Norris, 1986).

Two groups of theories exist regarding the relationship between top-down and bottom-up sources of information during speech processing. Interactive models (Gaskell & Marslen-Wilson, 1999; McClelland, 1991; McClelland, & Elman, 1986) posit that both sources of information flow bidirectionally, and therefore each influences the other throughout the process of lexical decision making. Conversely, autonomous or modular theories (Fodor, 1983; Forster, 1979; McQueen, Norris, & Cutler, 1999) posit that bottom-up acoustic-phonetic information is the primary source of information employed in decoding the speech signal, with top-down linguistic-contextual information playing a role in speech processing only after lexical decisions have been made. Theories diverge with respect to *when* contextual information becomes available to the listener and the role of feedback between linguistic-contextual and acoustic-phonetic information in processing speech. Regardless, considerable evidence suggests that linguistic-contextual information has an effect on listeners' ability to process speech (Duffy, Henderson, & Morris, 1989; Lucas, 1999; Norris, 1986; Tannenhaus & Lucas, 1987; Zwisterlood, 1989). The present study examined how different types of linguistic-contextual information influence intelligibility of dysarthric speech.

Lindblom (1990) proposed a model of mutuality in which he described reliance on top-down linguistic-contextual and bottom-up acoustic-phonetic information as inversely related for listeners of individuals with speech intelligibility deficits. That is, as bottom-up acoustic-phonetic information becomes less viable, listeners depend more on top-down linguistic-contextual information to compensate for the reduced information available from the speech signal. Conversely, as bottom-up acoustic-phonetic information becomes more viable, top-down linguistic-contextual information becomes less critical in achieving mutual understanding between speaker and listener because the speech signal itself carries all of the necessary information to ensure mutual understanding.

Speech Supplementation Strategies

Several studies (Beukelman & Yorkston, 1977; Carter, Yorkston, Strand, & Hammen, 1996; Crow & Enderby, 1989; Dongilli, 1994; Garcia & Cannito, 1996a, 1996b) have provided evidence for Lindblom's (1990) contention that top-down linguistic-contextual information, in the form of explicit cues, can enhance intelligibility of severely dysarthric speech. These consistent effects, although varying in magnitude, have lead to the clinical implementation of speech supplementation strategies that are designed to provide listeners with explicit top-down linguistic-contextual information to compensate for reduced intelligibility (Beukelman & Yorkston, 1977; Yorkston et al., 1999). Several types of speech supplementation strategies have been examined in the research literature. Of particular interest to the present study are alphabet supplementation, topic supplementation, and combined (topic and alphabet) supplementation.

Alphabet Supplementation

In clinical implementation, speakers employ alphabet supplementation by indicating the first letter of each word on an alphabet board as they speak it (Beukelman & Yorkston, 1977; Yorkston et al., 1988). Top-down linguistic-contextual information is provided in several ways through this strategy. First, listeners receive word-initial orthographic information that serves to constrain the pool of lexical options for each word, thus increasing the chance of selecting the appropriate word. Second, listeners receive temporal information regarding the onset of each new word. This may serve to facilitate parsing of acoustic-phonetic information into lexical units—a task that can be difficult with dysarthric speech. Finally, the addition of orthographic information to the acoustic signal adds redundancy to the message, which may further increase the listener's chance of understanding the speaker.

Across studies, alphabet supplementation has been shown to increase sentence intelligibility by an average of 15% to 44% (Beukelman & Yorkston, 1977; Crow & Enderby, 1989; Hustad & Morehouse, 1998). Three different effects have been demonstrated. First, when speakers implemented alphabet supplementation in conjunction with their speech, changes in the speech signal itself (such as reduced rate and increased word segmentation) occurred (Beukelman & Yorkston, 1977; Crow & Enderby, 1989). These acoustic-phonetic changes alone resulted in an average intelligibility increase of 15% (Crow & Enderby, 1989). Second, alphabet cues that were experimentally imposed on a habitual speech signal resulted in an average intelligibility increase of 26% (Hustad & Morehouse, 1998), suggesting that top-down linguistic-contextual information has an independent effect on intelligibility. Finally, when speakers employed alphabet supplementation and listeners were able to see these cues, intelligibility increased by an average of 44% (Beukelman & Yorkston, 1977).

Because each of these studies is the only one of its kind in the literature, these conclusions should be regarded cautiously. However, alphabet supplementation seems to have the potential to increase sentence intelligibility markedly. Additional research is needed to determine more conclusively the independent contributions of acoustic-phonetic information and linguistic-contextual information.

Topic Supplementation

When speakers employ topic supplementation, they indicate a referent or topic pertaining to a message before producing the message via natural speech (Hustad et al., 1998; Yorkston et al., 1999). Hustad and Beukelman (2000) suggest that topical information serves as a preparatory set for listeners, thereby helping them to anticipate and/or narrow expectations for the content of forthcoming messages. In turn, this top-down linguistic-contextual knowledge provided to the listener serves to enhance the speaker's intelligibility.

Aside from differences in the nature of the information provided, topic cues differ from alphabet cues in quantity of information provided to listeners. In topic supplementation, fewer cues are provided for each message (i.e., one topic for each sentence as compared with one letter for each word in alphabet supplementation). In addition, word-specific cues are not provided with topic supplementation, making the information received by the listener more global than that associated with alphabet supplementation.

Research focusing on the effects of topic cues at the sentence level has demonstrated average increases in intelligibility ranging from 5% to 9% (Carter et al., 1996; Dongilli, 1994; Garcia & Cannito, 1996a; Hustad & Beukelman, 1998) for speakers with severe dysarthria. Although there were methodological differences among studies regarding specificity of the topic cues provided to listeners, this did not appear to have a meaningful effect on intelligibility scores.

In a study examining effects of cues on word-level intelligibility, Beliveau and colleagues (1995) found that intelligibility associated with provision of alphabet and topic cues did not differ. However, comparison of published studies examining sentence intelligibility would seem to suggest that alphabet cues enhance sentence intelligibility more than topic cues. Because no studies have directly compared the effects of alphabet and topic cues on sentence intelligibility, conclusions are difficult to draw. Research is needed to confirm whether there is a difference in the relative benefit of either alphabet or topic cues on intelligibility of connected speech.

Combined (Topic and Alphabet) Supplementation

Combined supplementation involves simultaneous use of alphabet and topic cues. Listeners are first provided with the topic of a message, then alphabet cues are provided for the first letter of each word in the message. Presentation of both topic and alphabet cues together with the speech signal provides listeners with word-specific information via alphabet cues and broad contextual information via topic cues.

Research examining word-level stimuli has shown that combined cues result in higher intelligibility scores than alphabet cues, topic cues, and no cues (Beliveau et al., 1995). The effects of combined cues on sentence-level intelligibility relative to alphabet and no cues have not been studied. However, Hunter, Pring, and Martin (1991) found that provision of combined cues resulted in an average increase in intelligibility of 15% relative to topic cues. Research is necessary to determine the effects of combined cues as compared with other types of cues on sentence intelligibility.

Effects of Stimulus Length on Intelligibility

Communication occurs at a variety of linguistic levels, including word, sentence, and connected discourse. Speech intelligibility research has focused extensively on word (Beliveau et al., 1995; Beukelman & Yorkston, 1977; Giolas & Epstein, 1963; Miller, Heise, & Lichten, 1951) and sentence (Bagley, 1900-01; Beukelman & Yorkston, 1977; Garcia & Cannito, 1996a; Giolas & Epstein, 1963; Miller et al., 1951) levels, with little attention paid to discourse.

In general, research on speech intelligibility has shown differential effects of stimulus length. For example, sentences tend to be more intelligible than words presented in isolation (Miller et al., 1951; O'Neill, 1957; Sitler, Schiavetti, & Metz, 1983). One reason for this phenomenon may be that listeners are more readily able to apply intrinsic top-down linguistic-contextual knowledge to sentences than to individual words in isolation. In contrast, when listeners are presented with isolated words, they may be forced to rely more heavily on bottom-up acoustic-phonetic information because there is reduced opportunity to apply intrinsic top-down linguistic-contextual information.

If the same finding generalizes, it might be expected that discourse is more intelligible than both sentences and words. Narrative discourse differs from unrelated sentences in that meaning is cumulative, building from sentence to sentence in a cohesive fashion. As such, listeners may be able to apply intrinsic top-down linguistic-contextual knowledge even more readily with discourse than with sentences. Existing results are contradictory and therefore inconclusive, with studies both supporting and refuting this hypothesis. For example, Frearson (1985) found that sentences from the Assessment of Intelligibility of Dysarthric Speech (Yorkston & Beukelman,

1981) were more intelligible than multi-utterance spontaneous speech samples from individuals with mild to moderate dysarthria. However, methodological issues such as failure to control for linguistic content of spontaneous utterances call this finding into question. Using DECTalk synthesized speech, Drager (1999) found that intelligibility was significantly higher when target sentences were preceded by a short story than when target sentences were presented in isolation. Systematic controlled study is necessary to determine how narrative context affects intelligibility of dysarthric speech relative to sentential context.

The present study sought to answer three sets of questions:

1. Are there intelligibility differences among cue conditions (no cues, topic cues, alphabet cues, and combined cues) for unrelated sentence stimuli?
2. Are there intelligibility differences among cue conditions (no cues, topic cues, alphabet cues, and combined cues) for related sentence stimuli constituting a narrative?
3. Are there intelligibility differences between related and unrelated sentence stimuli for each cue condition?

The experimenters hypothesized that a similar pattern of pair-wise differences among cue conditions would be present for related and unrelated sentence stimuli. Because combined cues provided the greatest quantity of supplemental information to listeners (both word-specific cues and semantic cues regarding context), it was expected that intelligibility would be better for this condition than for any other. Experimenters anticipated that alphabet cues would yield better intelligibility scores than topic cues or no cues for two reasons. First, alphabet cues provide a greater quantity of information and, second, the information provided is specific to each word of the stimulus material, thus making alphabet cues stronger than topic cues. Finally, experimenters expected that when no supplemental cues were provided, intelligibility would be worse than in any other condition because of reduced top-down information available to listeners.

The experimenters anticipated that intelligibility for related sentences constituting narratives would be better for each cue condition than intelligibility for unrelated sentences. This was expected because related sentences would enable listeners to more readily apply *intrinsic* top-down knowledge in addition to available *extrinsic* top-down cues (topic, alphabet, combined), thus facilitating deductive processing and perhaps reducing processing demands imposed by dysarthric speech.

Method

Speakers With Dysarthria

Four women with severe dysarthria secondary to cerebral palsy served as speakers. Each indicated that she used speech as her primary mode of communication and a voice output communication device as a secondary communication strategy. Speakers met the following criteria: (a) speech intelligibility between 15% and 25% as measured by the Sentence Intelligibility Test (Yorkston et al., 1996), (b) native speakers of American English, (c) age between 19 and 46 years, (d) able to produce connected speech consisting of at least 8 consecutive words, and (e) able to repeat sentences of up to 8 words in length following a verbal model. Dysarthria type, rate of speech, and baseline intelligibility measures for each speaker are presented in Table 1.

Development of Speech Stimuli

Speech stimuli produced by individuals with dysarthria consisted of 16 narrative passages, each containing 10 sentences. The content of the narratives and their constituent sentences represented situational information common to native adult speakers of American English. Sentences within each passage were designed to be meaningful in isolation so that each sentence conveyed information pertaining to the narrative independently of all other sentences.

The length and content of each passage were equated on several different linguistic parameters.

Table 1. Characteristics of four speakers with dysarthria.

Characteristic	Speaker 1	Speaker 2	Speaker 3	Speaker 4
Age	19 years	24 years	46 years	42 years
Speech diagnosis	mixed spastic-athetoid dysarthria	mixed spastic-athetoid dysarthria	spastic dysarthria	spastic dysarthria
Rate of speech	24 words per minute	23 words per minute	38 words per minute	35 words per minute
Intelligibility on SIT	24%	16%	17%	15%

Each 10-sentence narrative contained two 5-word sentences, three 6-word sentences, three 7-word sentences, and two 8-word sentences—for a total of 65 words per narrative. Of those 65 words, there were 49 different words within each passage, yielding a type token ratio of .75. Each narrative had an average of 1.4 syllables per word, 9.0–9.1 syllables per sentence, and 6.5 words per sentence. In addition, each narrative contained 45 one-syllable words, 15 two-syllable words, 4 or 5 three-syllable words, and 0 or 1 four-syllable words. Reading level for each passage was a 5.7 grade equivalent. See Appendix A for a sample passage.

Predictability of narratives and their constituent sentences was not formally controlled in the development of speech stimuli. However, the semantic content and syntactic structure of narratives and individual sentences were intended to be predictable in that they followed standard English conventions. In order to control for unidentified differences in predictability and linguistic complexity and thus eliminate these as confounding variables, stimuli were randomly assigned across speakers and experimental conditions. Procedures for doing this are detailed below.

Development of Topic Cues

Topic cues were short, descriptive phrases that reflected the main idea of each narrative passage. Only one topic cue was provided for each narrative, so that a total of 16 different topic cues were employed for this experiment. Topic cues were constructed to be representative of the entire narrative as well as each individual sentence within the narrative. Sentence-topic pairs were presented in random order to 10 independent judges who were asked to rate the appropriateness of each of the 160 pairs in the corpus. Sentences and topics underwent slight alterations until 90% of judges (9 of 10) independently rated each sentence-topic pair as acceptable. That is, for each sentence employed in this study, at least 90% of judges rated the associated topic as appropriate. See Appendix A for sample topic cues and associated sentences.

Recording Speech Samples

Recordings of each speaker, producing the full corpus of 160 sentences, were made in a double-walled soundproof room. Digital audiotapes (DAT) were recorded using an HHb PDR1000 Portadat recorder with a sampling rate of 44.1 kHz and high pass filtering at 100 Hz. A Crown CM-312 microphone was positioned via headband so that it was 5 cm from the speaker's mouth regardless of head movement. Speakers were required to repeat each stimulus sentence following the experimenter's model. In addition, orthographic representations of stimulus sentences were provided on a computer screen placed in front of the speaker. Speakers were instructed to speak "naturally," as they would in habitual communication situations. Rate and prosody for each speaker were not controlled.

Stimulus Tape Preparation

Recordings were transferred from DAT to a personal computer via a digital-to-digital sound card (S/PDIF interface) (44.1 kHz sampling rate; 16-bit quantization). Using Sound Forge 4.5 computer software, individual sentences were edited to remove experimenter productions and extraneous comments. In addition, each sentence was amplitude normalized to 69 dB. Final signal-to-noise ratios were above 45 dB for all recordings.

Maintaining original sampling and quantization rates, sound files were imported into Adobe Premiere 5.1 (a digital video [DV] software package), which was used to add video images of each cue condition to the audio samples. In this manner, video images for topic cues, alphabet cues, combined cues, and no cues were separately associated with each sentence. Visual images for each cue condition were as follows:

1. Topic cues consisted of an orthographic representation of the target topic centered on the video screen and preceded by the utterance "The topic of this sentence is___." The topic of each sentence was shown for the duration of the spoken production, as indicated by individual waveforms.
2. Alphabet cues consisted of individual letters representing the initial grapheme of each word produced by the speaker presented in serial order. The entire alphabet was shown on an alphabet board arranged in an ABC fashion, similar to what might be employed in clinical practice. An individual grapheme representing the first letter of each word in the sentence was circled on the alphabet board as the speaker produced each word. Each initial grapheme was presented on the screen for the duration of the word. Word boundaries were identified through visual and auditory inspection of the acoustic waveform for each sentence. Word onsets were identified by the initiation of acoustic energy associated with each word. Word offsets were identified by the cessation of acoustic energy associated with each word. Because each speaker had somewhat different temporal characteristics to her speech, the duration of presentation for each word-initial grapheme varied among speakers and among words.
3. Combined cues consisted of both alphabet cues and topic cues. Topic cues were the same as those previously described; however, cues were placed on the

top of the screen to provide space for the alphabet board. For alphabet cues, again, the first letter of each word was highlighted on the alphabet board for the duration of that word, as described previously.

4. The no-cues condition consisted of a plain blue screen. No other visual information was available during this condition.

Sentences were sequenced according to specified randomization and counterbalancing procedures described below. Written instructions were presented via video image before each task. Similarly, transcription instructions were presented via video image between sentences during the second repetition of the stimuli. The final DV tapes presented to listeners were broadcast quality (DV-NTSC).

Randomization and Counterbalancing

Cue Conditions

All of the questions addressed in this study pertained to the effects of cue conditions. Therefore, it was critical that any type of order effect or learning effect be prevented. This was accomplished through application of a Latin Square counterbalancing scheme (Campbell & Stanley, 1963; Cook & Campbell, 1979; Kirk, 1995) in which all possible permutations of presentation order for cue conditions were presented across all listeners. Twenty-four unique stimulus tapes were made that collectively reflected each of the different orders of cue condition presentation possible. On each of the stimulus tapes, individual speakers appeared once in a given cue condition so that each listener saw four different speakers, each with a different cue condition. Appendix B shows order of cue conditions and speakers for each of the 24 stimulus tapes.

Speakers

Speakers were assigned to columns of the Latin Square described above in a systematic fashion so that across all tapes each speaker was presented in each cue condition 5–7 times. Furthermore, the order of presentation was controlled so that each speaker appeared first, second, third, and fourth in each cue condition 1–2 times across all tapes. Appendix C summarizes presentation order of cue conditions and speakers.

Stimuli

On each of the 24 stimulus tapes, individual sentences occurred only once. For the 8 intelligibility tasks (80 sentences) completed by each listener, 40 of the stimulus sentences were presented as cohesive narratives (related sentences condition). The other 40 sentences were drawn randomly from the pool of stimuli not used in the related sentences condition and were presented as lists of unrelated sentences. Assignment of each of the 16 stimulus passages to related and unrelated and sentence conditions was counterbalanced across stimulus tapes.

Length, complexity, and predictability of stimulus material were equated through randomization across cue conditions, stimulus cohesion conditions, and speakers so that each cell of the research design reflected data obtained from a random sampling of different sentences or narratives. Overall, each sentence from the pool of 160 was presented an average of 12 times (SD = 2.45) across all tapes and conditions. In addition, related sentences were presented first half of the time, and unrelated sentences were presented first the other half of the time across all tapes and conditions.

Nondisabled Listeners

Seventy-two nondisabled individuals served as listeners, so that an average of three listeners viewed each of the 24 stimulus tapes. Data reported in this study are part of a larger study (Hustad, 1999) and reflect results of eight different experimental conditions completed by each listener. These were intelligibility of *related* sentences with (1) alphabet cues, (2) topic cues, (3) combined cues and (4) no cues; and intelligibility of *unrelated* sentences with (5) alphabet cues, (6) topic cues, (7) combined cues, and (8) no cues.

Listeners met the following criteria: (a) no known hearing loss per self-report; (b) age between 18 and 31 years; (c) no more than incidental experience listening to or communicating with persons having communication disorders; (d) native speakers of American English; and (e) no identified language, learning, or cognitive disabilities per self-report. Listeners were drawn primarily from a pool of college students and had a mean age of 21 years (SD = 2.464). Gender composition was 8 males and 64 females. Because gender was not a variable of interest, no effort was made to balance the number of male and female listeners.

Experimental Task

Presentation of Stimuli

The digital audio-video signal was presented to small groups of listeners in a quiet listening environment. Listeners were seated at desks and positioned approximately 4–6 feet away from a 25-inch television monitor with one external speaker and a digital video cassette player attached to it. The television monitor was positioned at listeners' eye level (approximately 3.5 feet from the ground). The external speaker was positioned at listeners' chest level (approximately 2.5 feet from the ground), directly below the television monitor.

The peak loudness level of stimulus material, measured from where listeners were seated, was approximately 75 dB SPL, with average loudness being approximately 65 dB SPL. The ambient noise level in the room where the experiment occurred, measured at periodic intervals throughout the experiment, had a peak of 35 dB SPL, yielding an average signal-to-noise ratio of approximately 30 dB SPL.

Administration Instructions

Listeners were instructed that they would hear four women with cerebral palsy who were producing meaningful and grammatically correct lists of related sentences and unrelated sentences. Listeners were told that they would be able to hear the speakers, but not see their faces. Rather, they would see four different types of cues (no cues, topic cues, alphabet cues, and combined cues—not in this order), one associated with each speaker. Listeners were instructed that there would be two presentations of each stimulus sentence on the videotape. They were to watch and listen to the first presentation of 10 sentences and not to write anything on their score sheet. For the second presentation of the same 10 sentences, listeners were told to follow the instructions presented on the video monitor directing them to write down exactly what they thought the speaker said. They were encouraged to write down whatever they were able to understand, taking their best guess if they weren't sure what the speaker said. Listeners were told that the purpose of the study was to determine whether particular kinds of information helped listeners, like themselves, understand these speakers better. Finally, the experimenter explained that listeners could take as much time as necessary to transcribe each sentence and that breaks could be taken between experimental tasks if desired.

Similar procedures were followed for both related and unrelated sentence stimuli. However, before tasks involving related sentences forming a narrative, listeners were informed that what they were about to hear was a cohesive story. Likewise, for tasks involving unrelated sentences, listeners were informed a priori that they were about to hear a list of 10 unrelated sentences.

Scoring and Reliability

Intelligibility for each listener was scored as the number of words identified correctly divided by the number of words possible for each task. This number was then multiplied by 100 to compute percent intelligibility. Individual words were judged as incorrect or correct based on whether they matched the target word phonemically. Misspellings and homonyms were accepted as correct. Interlistener reliability was calculated for intelligibility scores for each speaker, cue condition, and stimulus cohesion condition using Guttman split-half reliability coefficients. Average interlistener reliability for each speaker and condition ranged from .92 to .96, for an experiment-wise average reliability coefficient of .93. These results indicate a high level of reliability among listeners within and between each condition.

Experimental Design

A 2 × 4 totally within-subjects repeated measures design (Kirk, 1995) was employed for this study. Accordingly, data from each of the 72 listeners made up each cell of the design. One within-subjects repeated measure was stimulus cohesion, and its two categories were related sentences and unrelated sentences. The other within-subjects repeated measure was cue condition, and its four categories were no cues (NC), topic cues (TC), alphabet cues (AC), and combined cues (CC).

Results

Because the research questions of interest were specified a priori, a planned contrast approach to ANOVA was employed in which only the contrasts of interest ($C = 16$) were subjected to statistical analysis (Hertzog & Rovine, 1985; Kirk, 1995; Marascuilo & Levin, 1983; Marascuilo & Serlin, 1988; Seaman, Levin, & Serlin, 1991). This approach is considered more conservative than the traditional omnibus ANOVA as fewer tests are performed, thus reducing the probability of Type I error. Accordingly, the experiment-wise alpha level for the present study was set at .05 and was partitioned using the Dunn-Bonferroni procedure (Marascuilo & Serlin, 1988). As such, each of the 16 contrasts tested was allotted an alpha of .003. Statistical results for each planned contrast are shown in Table 2 and will be presented according to the three groups of questions addressed in this study.

Cue Conditions and Random Sentence Stimuli

Mean intelligibility scores for random sentence stimuli in each cue condition across all four speakers were as follows: 18.49% (SD = 11.29%) for no cues, 28.60% (SD = 13.37%) for topic cues, 36.94% (SD = 13.40%) for alphabet cues, and 51.81% (SD = 16.19%) for combined cues. These data are displayed graphically in Figure 1.

Statistical results indicated that combined cues had significantly higher intelligibility scores than alphabet cues ($t = 6.318$, $p < .001$), topic cues ($t = 10.186$, $p < .001$), and no cues ($t = 14.665$, $p < .001$). In addition, the no-cues condition had significantly lower intelligibility scores than alphabet cues ($t = 9.914$, $p < .001$) and topic cues ($t = 6.126$, $p < .001$). Finally, alphabet cues had

Table 2. Planned contrasts (C = 16) for repeated measures (CCRS = combined cues related sentences; ACRS = alphabet cues related sentences; TCRS = topic cues related sentences; NCRS = no cues related sentences; CCUS = combined cues unrelated sentences, ACUS = alphabet cues unrelated sentences; TCUS = topic cues unrelated sentences; NCUS = no cues unrelated sentences).

Contrast	Mean difference	*df*	Standard error for contrast	*t*
CCUS – ACUS	1486	71	0235	6 318*
CCUS – TCUS	.2321	71	.0228	10.186*
CCUS – NCUS	.3332	71	.0227	14.665*
ACUS – NCUS	1846	71	0186	9.914*
ACUS – TCUS	0835	71	0201	4.150*
TCUS – NCUS	1011	71	.0165	6 126*
CCRS – ACRS	1168	71	.0267	4 375*
CCRS – TCRS	2453	71	.0313	7.831*
CCRS – NCRS	.3611	71	.0241	14.982*
ACRS – NCRS	2443	71	.0272	8 968*
ACRS – TCRS	1285	71	.0313	4.106*
TCRS – NCRS	.1158	71	0263	4.411*
NCRS – NCUS	.0126	71	.0141	.897
TCRS – TCUS	.0274	71	.0239	1 145
ACRS – ACUS	0724	71	0212	3.420*
CCRS – CCUS	.0406	71	.0203	2.002

* Statistical significance at $p < .001$

significantly higher intelligibility scores than topic cues ($t = 4.150$, $p < .001$).

Cue Conditions and Related Sentence Stimuli

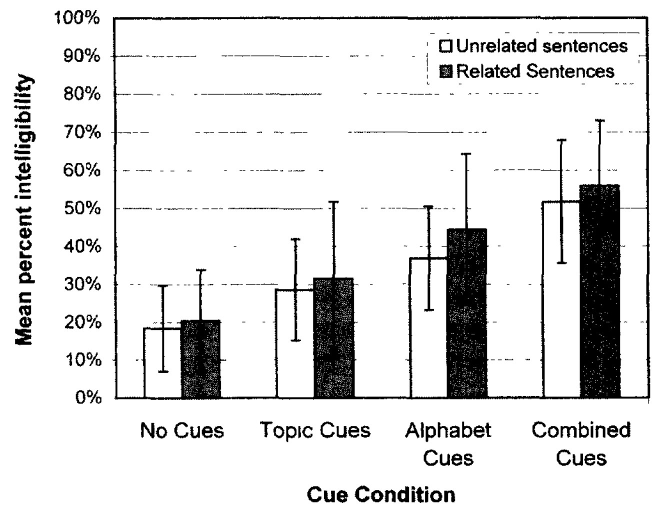
Intelligibility results for related sentences forming a narrative were nearly identical to those observed for random sentences in each cue condition. Across speakers, means were as follows: 20.41% (*SD* = 12.00%) for no cues, 31.55% (*SD* = 15.18%) for topic cues, 44.45% (*SD* = 18.86%) for alphabet cues, and 55.99% (*SD* = 17.93%) for combined cues. Data are displayed graphically in Figure 1.

Statistical results indicated that combined cues had significantly higher intelligibility scores than alphabet cues ($t = 4.375$, $p < .001$), topic cues ($t = 7.831$, $p < .001$), and no cues ($t = 14.982$, $p < .001$). In addition, the no-cues condition had significantly lower intelligibility scores than alphabet cues ($t = 8.968$, $p < .001$) and topic cues ($t = 4.411$, $p < .001$). Finally, alphabet cues had significantly higher intelligibility scores than topic cues ($t = 4.106$, $p < .001$).

Stimulus Cohesion

Mean intelligibility differences across speakers for cohesive narrative stimuli and random sentence stimuli

Figure 1. Mean percent intelligibility (±*SD*) by cue condition for related and unrelated sentences.



for each cue condition were as follows: 1.26% (*SD* = .119%) for no cues, 2.74% (*SD* = .203%) for topic cues, 7.24% (*SD* = .179%) for alphabet cues, and 4.06% (*SD* =.172%) for combined cues. Although means for cohesive narrative stimuli were higher than those for random sentence stimuli, this difference was significant only for alphabet cues ($t = 3.420$, $p < .001$).

Descriptive Differences Among Cue Conditions for Individual Speakers

Examination of individual speaker data suggests some descriptive differences in the effects of cues on intelligibility. Two findings were consistent among individual speakers and cohesion conditions: (1) the combined-cues condition seemed to have the highest intelligibility both for narratives and sentences, and (2) the no-cues condition seemed to have the lowest intelligibility both for narratives and sentences. Individual speaker data are displayed in tabular form for related and unrelated sentences in Table 3.

Discussion

Effects of Cue Conditions

In general, results of the present study show that when listeners are presented with the same acoustic-phonetic speech signal in conjunction with different kinds of explicit top-down linguistic-contextual cues, intelligibility is altered significantly. The present study differed from existing research in this area in that all cues were superimposed on the habitual speech signal of the speakers with dysarthria and therefore served exclusively as a source of linguistic-contextual top-down information for

Table 3. Intelligibility data for individual speakers by cue condition (NC = No Cues; TC = Topic Cues; AC = Alphabet Cues; CC = Combined Cues) and sentence cohesion (unrelated and related sentences).

Cue Condition		Speaker 1		Speaker 2		Speaker 3		Speaker 4		All speakers (weighted)	
		unrelated sentences	related sentences	unrelated sentences	related sentences	unrelated sentences	related sentences	unrelated sentences	related sentences	unrelated sentences	related sentences
NC	*M*	14.69	21.08	11.50	11.25	29.94	30.13	18.74	19 17	18 49	20 41
	SD	7.74	12.47	10.11	8 59	9 54	15 17	8 96	11.78	11 29	12.00
	Range	5–28	5–32	0–34	0–28	14–46	6–55	3–32	2–46	0–46	0–55
	N	13	13	20	20	16	16	23	23	72	72
TC	*M*	24.05	22.37	21.42	17.37	37 26	50.95	32.47	35.53	28.60	31.55
	SD	6.47	15.59	12.47	12.45	13 17	18.15	14.61	14.54	13 37	15 18
	Range	11–34	0–55	2–40	0–45	15–63	18–88	14–60	14–62	2–63	0–88
	N	19	19	19	19	19	19	15	15	72	72
AC	*M*	37.15	39.75	34.39	39 00	43.71	55 94	32.65	43.12	36.94	44 45
	SD	10.01	18.57	10.34	16 89	16.73	19 30	14.43	20.70	13.40	18 86
	Range	15–51	15–82	15–58	17–66	14–69	23–83	15–66	11–72	14–69	11–83
	N	20	20	18	18	17	17	17	17	72	72
CC	*M*	46.45	55.15	52.87	52 27	55.90	62.65	53.77	53.88	51.81	55 99
	SD	15.46	16.27	16.78	22 81	17 26	15.16	15 78	17 50	16.18	17 93
	Range	26–82	9–75	31–80	20–89	17–88	31–89	25–86	15–77	22–88	9–89
	N	20	20	15	15	20	20	17	17	72	72

listeners. Specifically, the present study shows that alphabet cues, topic cues, and combined cues each enhance intelligibility of unrelated sentences and related sentences relative to a control condition in which no cues were provided to listeners. Mean data across all four speakers show that combined cues resulted in significantly higher intelligibility scores than any other cue condition, the no-cues control condition resulted in significantly lower intelligibility scores than any other cue condition, and alphabet cues yielded higher intelligibility scores than topic cues. Also noteworthy was that there was marked variability among listeners within each of the conditions, with descriptively greater variability noted in each of the cue conditions (TC, AC, CC) than in the no cues condition. Although the overall pattern of results was the same for unrelated sentences and related sentences constituting a narrative, examination of descriptive data suggests that there may have been more variability among listeners for related sentences than for unrelated sentences. This variability suggests marked individual differences among listeners in ability to decode the speech of individuals with severe dysarthria. In spite of this variability, overall findings of the present study are consistent with Lindblom's (1990) model of mutuality.

Alphabet and Topic Cues

In the present study, provision of alphabet cues significantly increased the average intelligibility of unrelated and related sentences relative to the no-cues condition. The magnitude of this effect was 24% and 18% respectively. This result extends the exiting literature (Beukelman & Yorkston, 1977; Crow & Enderby, 1989) and demonstrates that top-down linguistic-contextual cues have an effect on intelligibility that is independent of speech production changes that may result when speakers actually employ alphabet supplementation.

Topic cues were also shown to increase intelligibility for unrelated and related sentences relative to the no cues control condition in the present study. The size of this effect—10% and 11% respectively—was consistent with existing studies examining the effects of topic cues on predictable sentences (Carter et al., 1996; Dongilli, 1994; Garcia & Cannito, 1996a; Hustad & Beukelman, 1998).

Alphabet cues yielded higher intelligibility scores than topic cues for both related and unrelated sentences in the present study. The magnitude of this effect was 8% and 13% respectively. This finding differs from the results of Beliveau et al. (1995), who found that there was no difference between topic and alphabet cues for single words. There are several possible explanations for this discrepancy. In the Beliveau et al. study, isolated word stimuli were employed with one cue (topic or alphabetic) provided for each word, making the number of cues equivalent between the two conditions. In the present study, sentence-length stimuli were employed. For the alphabet cues condition, one letter was provided for each word of target sentences. However, for the topic cues condition, one topic was provided for each sentence—resulting in markedly fewer topics per word than in the

Beliveau et al. study. This difference in number of topics per word provided to listeners may have weakened the effects of topic cues in the present study. Together, the findings of Beliveau et al. and the present study seem to suggest that topic cues and alphabet cues may have a similar effect when they are provided with the same frequency (for each word of a message). However, when topic cues are provided at the utterance level, as would likely be the case in clinical implementation, the present study shows that they are less effective than alphabet cues.

Combined Cues

For unrelated and related sentences, the present study shows that intelligibility was significantly higher for combined cues than for no cues, topic cues, or alphabet cues. Descriptive data indicate that the advantage of combined cues over any other cue condition was remarkable, ranging from 12% to 36% for related sentences and from 14% to 33% for unrelated sentences. In general, the findings from this study were consistent with those of Hunter et al. (1991) and Beliveau et al. (1995). However, the magnitude of observed effects was larger for the present study than both previous studies. This may be due to the nature of the topic cues provided to listeners. Hunter et al. provided their listeners with a single context-setting word before presentation of stimulus sentences, and Beliveau et al. provided listeners with a single broad semantic category. In the present study, listeners were provided with topic phrases that were specific to each narrative and displayed for the duration of each sentence. Topic cues provided in the present study seem to have been more specific than those provided in previous studies, thereby resulting in greater benefit from combined cues.

Stimulus Cohesion

In general, results of the present study showed intelligibility of related sentences forming a narrative did not differ from intelligibility of unrelated sentences for no cues, topic cues, and combined cues. However, when alphabet cues were provided to listeners, intelligibility was higher for related sentences than for unrelated sentences by 7%. There are several possible explanations for these findings.

Alphabet Cues and No Cues

In the alphabet cues condition, listeners were given only word-initial orthographic cues for each word produced by the speaker. When presented with related sentences and alphabet cues, listeners may have been able to infer topical information via intrinsic top-down linguistic contextual knowledge because of the cohesive nature of the stimulus material. This, in conjunction with alphabet cues, may have resulted in what was functionally a weaker version of the combined-cues condition, with inferred rather than explicit topic knowledge. Conversely, in the unrelated-sentences condition, listeners may have been forced to rely on less information—only alphabet cues—because inferring topical information would likely be more difficult as topics changed from sentence to sentence. As a result, related sentences offered an advantage over unrelated sentences for the alphabet cues condition.

Generalization of the conclusions discussed above to the no cues condition would suggest that related sentences should have higher intelligibility than unrelated sentences. However, this was not the case in the present study. It is important to note that average intelligibility across all 4 speakers for the no cues condition was 18.5% (11.5%–29.9% across speakers) for unrelated sentences and 20.4% (11.25%–30% across all speakers) for related sentences. Average intelligibility scores were at least double these for the alphabet cues condition. The severe intelligibility deficits evidenced in all speakers under study within the no cues condition may have served to tax listeners to such an extent that they were not able to understand well enough to apply intrinsic top-down knowledge during the related-sentences condition. Consequently, related sentences offered no advantage for intelligibility over unrelated sentences in the no cues condition. This conclusion is purely speculative, and future research examining speakers with less severe dysarthria is necessary to substantiate this supposition.

Topic Cues and Combined Cues

For topic and combined cues, the presence of topic cues may provide an explanation for the lack of a significant difference between related and unrelated sentences in both conditions. For unrelated sentences, explicit topic cues served to provide new information regarding the context of each utterance for both topic and combined cues conditions. However, for related sentences, provision of explicit topic cues may have been more a source of redundancy than of new information because the same topic cue was provided for each sentence in this condition. As a result, topic cues may have had a greater influence on intelligibility of unrelated sentences than on related sentences, thus reducing any inherent benefit in top-down intrinsic linguistic-contextual knowledge available when listeners are presented with related sentences forming a narrative. That is, top-down linguistic-contextual knowledge may have been equated between related and unrelated sentence conditions via topic cues, resulting in similar intelligibility scores.

Generally, results of the present study do not support either of the published studies (Drager, 1999;

Frearson, 1985) examining intelligibility of discourse compared with unrelated sentences. However, results of the present study examining alphabet cues support the findings of Drager (1999) with synthesized speech. Methodological differences prevent direct comparison among studies, and generalization should be made cautiously. Further research is needed in this area.

In conclusion, results of the present study support and extend Lindblom's (1990) model of mutuality. For speakers with severe intelligibility challenges, top-down linguistic-contextual information of any kind that is provided to listeners enhances intelligibility markedly. In addition, this study demonstrated that strategies providing a greater quantity of top-down linguistic-contextual information in the form of supplemental cues enhanced intelligibility to a greater extent than strategies that provided fewer explicit cues (e.g., combined cues were better than alphabet cues; alphabet cues were better than topic cues). This study provides further evidence that context has a powerful effect on intelligibility

Clinical Implications and Future Directions

Results of the present study have a number of clinical implications for individuals who have severe dysarthria and choose to use speech as their primary mode of communication. First, this study supports previous studies that show provision of top-down linguistic-contextual information to listeners enhances intelligibility. For maximal increases in intelligibility, findings from this study suggest that speakers should employ a combined cueing strategy in which they provide their listeners both with the topic of the message and the first letter of each word as it is spoken. If speakers are unable to employ a combined cueing strategy to supplement their speech, findings from this study suggest that alphabet cues enhance intelligibility to a greater extent than topic cues.

This study was experimental in nature and, as such, findings may not generalize directly to clinical situations. For instance, alphabet cues were experimentally imposed on the habitual speech of the persons with dysarthria for this study. In clinical practice, implementation of alphabet supplementation or a combined cueing strategy would require the speaker to point physically to the first letter of each word as he or she speaks it. The physical act of pointing to an alphabet board may have an effect on speech-production skills for some speakers with motor impairment. In addition, learning demands for employing alphabet and topic cues and the actual effectiveness of these strategies in spontaneous speaking situations are unclear. Further research is necessary to generalize findings from the present study to clinical implementation.

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Contact author: Katherine C. Hustad, PhD, Department of Communication Disorders, The Pennsylvania State University, 110 Moore Building, University Park, PA 16803. Email: kch2@psu.edu

Appendix A. Sample Lists of Unrelated and Related Sentences With Topic Cues.

Rain caused severe flash floods.	natural disaster
The guest list is very long.	wedding plans
Everyone in the family made new friends.	relocating to a new city
One airline has lost his luggage three times	travel problems
They have a cottage on the ocean.	vacation at the seashore
Katherine and David wanted to buy a house.	acquiring a new home
It is a national holiday.	independence day
The home team won by one touchdown.	sports outing
Teachers begin preparing a week early.	beginning a new school year
Jason needed to buy a car.	purchasing a vehicle
Robert and Kelly bought a sailboat.	ocean voyage
Every weekend they sailed in the sea.	ocean voyage
Together they became expert sailors.	ocean voyage
Traveling around the world was their dream.	ocean voyage
The voyage might take an entire year.	ocean voyage
A long vacation from work would be needed.	ocean voyage
Their route was carefully planned.	ocean voyage
The first stop would be Europe.	ocean voyage
China would be their last stop.	ocean voyage
A journal would help them remember their trip.	ocean voyage

Appendix B. Latin Square Counterbalancing and Randomization Scheme for Stimulus Tapes.

Tape	First condition / speaker	Second condition / speaker	Third condition / speaker	Fourth condition / speaker
Tape 1	AC / Speaker 1	CC / Speaker 2	NC / Speaker 4	TC / Speaker 3
Tape 2	AC / Speaker 2	CC / Speaker 1	TC / Speaker 4	NC / Speaker 3
Tape 3	AC / Speaker 1	NC / Speaker 4	CC / Speaker 3	TC / Speaker 2
Tape 4	AC / Speaker 4	NC / Speaker 3	TC / Speaker 1	CC / Speaker 2
Tape 5	AC / Speaker 3	TC / Speaker 2	NC / Speaker 1	CC / Speaker 4
Tape 6	AC / Speaker 4	TC / Speaker 3	CC / Speaker 1	NC / Speaker 2
Tape 7	CC / Speaker 4	NC / Speaker 3	TC / Speaker 2	AC / Speaker 1
Tape 8	CC / Speaker 1	NC / Speaker 2	AC / Speaker 3	TC / Speaker 4
Tape 9	NC / Speaker 1	AC / Speaker 2	NC / Speaker 3	TC / Speaker 4
Tape 10	CC / Speaker 2	AC / Speaker 1	TC / Speaker 3	NC / Speaker 4
Tape 11	CC / Speaker 3	TC / Speaker 1	AC / Speaker 4	NC / Speaker 2
Tape 12	CC / Speaker 4	TC / Speaker 2	NC / Speaker 1	AC / Speaker 3
Tape 13	NC / Speaker 3	TC / Speaker 1	AC / Speaker 2	CC / Speaker 4
Tape 14	NC / Speaker 1	TC / Speaker 4	CC / Speaker 3	AC / Speaker 2
Tape 15	NC / Speaker 2	CC / Speaker 4	AC / Speaker 3	TC / Speaker 1
Tape 16	NC / Speaker 4	CC / Speaker 2	TC / Speaker 3	AC / Speaker 1
Tape 17	NC / Speaker 1	AC / Speaker 3	TC / Speaker 4	CC / Speaker 2
Tape 18	NC / Speaker 2	AC / Speaker 3	CC / Speaker 4	TC / Speaker 1
Tape 19	TC / Speaker 1	AC / Speaker 4	CC / Speaker 2	NC / Speaker 3
Tape 20	TC / Speaker 3	AC / Speaker 4	NC / Speaker 2	CC / Speaker 1
Tape 21	TC / Speaker 4	CC / Speaker 3	AC / Speaker 2	NC / Speaker 1
Tape 22	TC / Speaker 3	CC / Speaker 1	NC / Speaker 2	AC / Speaker 4
Tape 23	TC / Speaker 2	NC / Speaker 4	AC / Speaker 1	CC / Speaker 3
Tape 24	TC / Speaker 2	NC / Speaker 1	CC / Speaker 4	AC / Speaker 3

Appendix C. Frequency of occurrence of speakers across all stimulus tapes by order (first, second, third, and fourth) and cue condition (NC = No Cues, TC = Topic Cues, AC = Alphabet Cues, CC = Combined Cues).

		First	Second	Third	Fourth			First	Second	Third	Fourth
NC	Speaker 1	2	1	2	1	AC	Speaker 1	2	1	1	2
	Speaker 2	2	1	2	2		Speaker 2	1	1	2	1
	Speaker 4	1	2	1	1		Speaker 4	2	2	1	1
	Speaker 3	1	2	1	2		Speaker 3	1	2	2	2
	Overall	6	6	6	6		Overall	6	6	6	6
TC	Speaker 1	1	2	1	2	CC	Speaker 1	2	2	1	1
	Speaker 2	2	2	1	1		Speaker 2	1	2	1	2
	Speaker 4	1	1	2	2		Speaker 4	2	1	2	2
	Speaker 3	2	1	2	1		Speaker 3	1	1	2	1
	Overall	6	6	6	6		Overall	6	6	6	6