Contribution of Two Sources of Listener Knowledge to Intelligibility of Speakers With Cerebral Palsy

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Purpose: This study examined the independent and combined effects of two sources of linguistic knowledge (alphabet cues and semantic predictability) on the intelligibility of speakers with dysarthria. The study also examined the extent to which each source of knowledge accounted for variability in intelligibility gains.
Method: Eight speakers with cerebral palsy and dysarthria contributed speech samples, and 128 listeners transcribed the speech samples (16 listeners per speaker) in 4 different conditions (no cues and unpredictable sentences; no cues and predictable sentences; alphabet cues and unpredictable sentences; alphabet cues and predictable sentences). Listener transcription results were the dependent variable and were scored as the percentage of words identified correctly by listeners.
Results: Both alphabet cues and semantic predictability made independent and overlapping contributions to intelligibility. In addition, alphabet cues accounted for more of the variability in gain scores than semantic predictability. Inseparable joint effects from the two sources of knowledge also made an important contribution to intelligibility.
Conclusion: Alphabet cues may be a more powerful source of information for resolving lexical ambiguity than semantic predictability for listeners who are faced with dysarthric speech.

KEY WORDS: speech intelligibility, speech perception, dysarthria, cerebral palsy

Individuals with dysarthria frequently have reduced speech intelligibility (Darley, Aronson, & Brown, 1969; Yorkston, Beukelman, Strand, & Bell, 1999). Although intelligibility problems are commonly regarded as a characteristic of the speaker, they are also directly influenced by the listener and what he or she hears when presented with a particular speech signal. In fact, studies show that there is often marked variability, as indicated by large variances in intelligibility scores, in what different listeners are able to decipher given the same speech sample (see Beukelman, Fager, Ullman, Hanson, & Logemann, 2002; Garcia & Dagenais, 1998; Hustad, Jones, & Dailey, 2003; Liss, Spitzer, Caviness, & Adler, 2002). The majority of research efforts in dysarthria have focused on speaker-related variables and their contribution to intelligibility, with far less effort directed toward the study of listener-related variables. However, both listener-related variables and speaker-related variables clearly play important, and perhaps connected, roles in the explication of factors that influence intelligibility of dysarthric speech (Connolly, 1986; DePaul & Kent, 2000; Kent, Weismer, Kent, & Rosenbek, 1989; Weismer & Martin, 1992; Yorkston, Strand, & Kennedy, 1996). This article focuses on two different listener-related variables and their contribution to intelligibility of dysarthric speech.

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Signal-Independent Knowledge and Intelligibility

Lindblom (1990a) emphasized that "speech perception is not driven exclusively by the signal. Linguistic and other knowledge influences what we hear" (p. 222). Indeed, listeners routinely impose various kinds of stored knowledge on the speech signal, and this ability makes speech perception robust, even when the acoustic signal is degraded and listeners are faced with partial information (Lindblom, 1990a, 1990b, 1996). Lindblom (1990a) referred to what is "stored in the listener's brain" (p. 225) as signal-independent information. There are many potential subtypes of signal-independent information that listeners possess. For example, listeners have stored knowledge about linguistic and phonetic properties of their native language, paralinguistic behaviors, and world or experiential events. These privately held types of knowledge are independent of the speech signal only until the listener needs to make sense of a spoken utterance. When a signal is presented to the listener, it invokes online and postperceptual application of different types of knowledge. When this knowledge is actually applied to the signal by the listener, it is no longer truly signal-independent because the signal itself directs application of different types of knowledge at different time points during perception. Thus, application of signal-independent knowledge becomes a "signal-complementary" process (Lindblom, 1990b). Throughout this article, the term *signal-independent* refers to listeners' stored knowledge as well as signal-complementary application of stored knowledge.

In a description of the mutuality of speaker–listener interaction, Lindblom (1990a) hypothesized that there is an inverse relationship between speaker-related variables (i.e., the acoustic signal produced by the speaker) and listener-related variables (i.e., signal-independent knowledge possessed by the listener)—that is, the better the acoustic signal, the less important signal-independent knowledge is to achievement of mutual understanding between speaker and listener. When the acoustic signal is compromised or reduced, the listener compensates by drawing to a greater extent on signal-independent knowledge to decipher the message.

Various lines of evidence support the notion that signal-independent knowledge plays an important role in speech intelligibility. For example, experimental studies have demonstrated that when the speech signal is degraded, intelligibility scores are generally lower for single-word stimuli than for sentences (Miller, Heise, & Lichten, 1951; O'Neill, 1957; Salasoo & Pisoni, 1985; Sitler, Schiavetti, & Metz, 1983; Yorkston, & Beukelman, 1978) and narratives (Hustad, in press). One explanation for this finding is that when faced with isolated words devoid of linguistic context, listeners are unable to apply certain types of signal-independent linguistic knowledge (e.g., semantic and syntactic knowledge). Because fewer sources of signal-independent knowledge are available to aid in deciphering the degraded signal, speech intelligibility is reduced.

Research has also shown that semantic predictability influences intelligibility, with less predictable sentences eliciting lower intelligibility scores than more predictable sentences (Boothroyd & Nittrouer, 1988; Duffy & Giolas, 1974; Garcia & Cannito, 1996; Kalikow, Stevens, & Elliot, 1977). One likely reason for this finding is that when semantic predictability is reduced, listeners cannot take full advantage of their stored semantic knowledge to aid in deciphering the speech signal. Again, because application of semantic knowledge is constrained, there are fewer sources of signal-independent knowledge that are useful for deciphering the signal, which ultimately results in reduced intelligibility scores.

Collectively, studies indicate that listeners' linguistic knowledge plays an important role in speech processing, especially when speech intelligibility is compromised, as is often the case in speakers with dysarthria. In addition to the impact of semantic predictability on intelligibility of speakers with dysarthria, another question of interest for this study relates to the effect of speech supplementation strategies, specifically alphabet cues, on what listeners hear.

Speech Supplementation Cues as a Form of Signal-Independent Information

Speech supplementation strategies are a group of interventions that combine the use of supplemental augmentative cues with natural speech to improve speech intelligibility in individuals with dysarthria. Examples of speech supplementation strategies include iconic gestures (Garcia & Cannito, 1996; Garcia & Dagenais, 1998; Hustad & Garcia, 2005), topic cues (Beukelman et al., 2002; Dongilli, 1994; Hustad & Beukelman, 2001; Hustad et al., 2003), and alphabet cues (Beukelman & Yorkston, 1979; Beukelman et al., 2002; Hustad & Beukelman, 2001; Hustad et al., 2003). Hustad and colleagues (2003) suggested that speech supplementation strategies could be considered a type of signal-independent information that is different from private or intrinsic knowledge possessed by listeners. In particular, speech supplementation strategies provide additional externally imposed cues that the listener can use to help decipher the speech signal. Of interest for the present study was the impact of alphabet cues as a supplemental source of linguistic information.

Alphabet supplementation is a strategy in which speakers use an alphabet board to indicate the first letter of each word while simultaneously speaking. Several studies have examined the effects of alphabet cues on intelligibility of sentences. These studies show that alphabet cues can improve intelligibility between 5% and 69%, with average gains being approximately 25% (Beukelman et al., 2002; Beukelman & Yorkston, 1977; Crow & Enderby, 1989; Hustad & Beukelman, 2001; Hustad et al., 2003; Hustad & Garcia, 2002, 2005).

Although the various studies have used different methodologies, different speech stimuli, and different participant populations, three main conclusions emerge from the collective body of research. First, when speakers physically point to the first letter of each word while simultaneously speaking, rate of speech is reduced (Beukelman et al., 2002; Hustad et al., 2003; Hustad & Garcia, 2005) and intelligibility is increased, even when alphabet cues are concealed (Beukelman & Yorkston, 1977; Crow & Enderby, 1989; Hustad & Garcia, 2005). Thus, production-based, or signal-dependent, changes in the speech signal also seem to occur. The exact nature of these production changes, beyond basic temporal features, is yet unknown.

The second conclusion suggested by the alphabet supplementation literature is that when speakers point to letters and the alphabet cues are visible to listeners, intelligibility is increased to a greater extent than when alphabet cues are concealed (Beukelman & Yorkston, 1977; Hustad & Garcia, 2005). This finding suggests that acoustic changes coupled with listener application of signal-independent knowledge play a role in enhancing intelligibility. However, the independent and overlapping contributions of the various factors have not been studied in ways that permit clean parsing of effects.

Finally, the alphabet supplementation literature has shown that when alphabet cues are superimposed on the habitual speech of individuals with dysarthria, intelligibility is increased (Beliveau, Hodge, & Hagler, 1995; Hustad & Beukelman, 2001). This finding suggests that the linguistic information provided by alphabet cues has an independent effect on intelligibility (Hustad & Beukelman, 2001). Alphabet cues alone may help listeners decipher the speech signal more readily because they reduce lexical ambiguity. In addition, Hustad and Beukelman (2001) suggested that the information provided by alphabet cues may enhance listeners' success in applying other types of linguistic knowledge (such as semantic knowledge), which in turn results in increased speech intelligibility. In the present article, this possibility is considered through manipulation of semantic predictability of messages and provision of experimentally imposed alphabet cues. The following specific research questions were addressed:

1. What is the independent effect of semantic predictability on intelligibility of dysarthric speech?
2. What is the independent effect of experimentally imposed alphabet cues on intelligibility of dysarthric speech?
3. What is the joint impact of semantic predictability and alphabet cues on intelligibility of dysarthric speech?
4. To what extent is the overall benefit from both semantic predictability and alphabet cues attributable to the independent effects of semantic predictability, the independent effects of alphabet cues, and the joint influence of both variables?

Method

Participants

Two groups of participants were involved in this study: speakers with dysarthria and everyday listeners (Klasner & Yorkston, 2005). Speakers with dysarthria produced speech samples, which were then played for listeners who transcribed what they heard. The dependent variable examined in this study was listener transcription data.

Speakers with dysarthria. Eight individuals who had a medical diagnosis of cerebral palsy and subsequent dysarthria participated as speakers. Dysarthria severity varied among the speakers, from mild to severe, as determined by scores on the Sentence Intelligibility Test (SIT; Yorkston, Beukelman, & Tice, 1996). Demographic information for the speakers, including age, gender, dysarthria diagnosis, dysarthria severity, and SIT score, is provided in Table 1. All speakers were required to (a) use American English as their first and primary language; (b) have normal hearing per self-report; (c) have scores between 20% and 85% on the SIT; (d) be between 18 and 60 years of age; (e) be able to produce connected speech consisting of at least eight consecutive words; and (f) be able to repeat sentences of up to eight words in length following a verbal model.

Listeners. Sixteen different individuals watched and listened to each speaker with dysarthria, for a total of 128 listeners across the 8 speakers. Different listeners were randomly assigned to each speaker so that the same stimulus material could be used for each speaker without the possibility of a learning effect. All listeners were required to (a) use American English as their first and primary language; (b) pass a pure-tone hearing screening at 20 dB SPL for 250 Hz, 500 Hz, 1 kHz, 4 kHz, and 6 kHz bilaterally; (c) have no more than incidental experience listening to or communicating with persons having communication disorders; (d) be between 18 and 45 years of age; and (e) have no identified language, learning, or cognitive disabilities per self-report. Listeners were recruited from the local community and included university students as well as community members who

Table 1. Demographic information for speakers with cerebral palsy and dysarthria.

Speaker	Age	Gender	Dysarthria diagnosis	Dysarthria severity	SIT score
A	33	M	Mixed spastic–hyperkinetic	Severe	20%
B	33	F	Mixed spastic–ataxic	Severe	20%
C	42	F	Spastic	Severe	27%
D	33	F	Spastic	Moderate	50%
E	55	M	Spastic	Mild–Moderate	75%
F	32	F	Spastic	Mild	83%
G	37	M	Spastic	Mild–Moderate	75%
H	34	M	Hyperkinetic	Mild	80%

Note. M = male; F = female.

were not affiliated with the university. Listeners had a mean age of 22.8 years (*SD* = 4.4). Half of the participants assigned to each speaker were male, and half were female.

Materials

Speakers with dysarthria produced 20 Haskins sentences (Nye & Gaitenby, 1974). Sentences were designed to be semantically anomalous (implausible) in nature; however, all sentences followed a similar syntactic structure (subject–verb–object) and were six words in length.

Speakers also produced 20 sentences taken from Hustad and Beukelman (2001, 2002). Sentences were designed to be predictable in nature, using Standard American English conventions for content, form, and use of language. All sentences were 5–6 words in length and were selected from a larger corpus of sentences based on similarity to the Haskins sentences with regard to length. Examples of predictable and semantically anomalous sentences are provided in the Appendix.

Procedures

Recording speakers. Speakers were audio and video recorded on digital audiotape and digital videotape while they produced the target stimuli. Recordings took place in a quiet setting, either within the speaker's home or in a sound-attenuating room in the laboratory. Speakers wore a low-profile, unidirectional, head-mounted microphone positioned 5 cm from the mouth. To assure that differences in reading fluency and visual acuity did not affect the production of target sentences, speakers produced individual sentences following the experimenter's model. In addition, orthographic representations of stimulus sentences were also provided on a computer screen positioned in front of the speakers. Speakers produced each sentence verbatim, including all constituent words. They were asked to repeat any sentence that did not include all words per the experimenter's perceptual judgment. Repetitions were required on fewer than 5% of stimulus sentences across all speakers. Speakers were encouraged to speak naturally, as they would in real communication situations.

Preparing speech samples for playback to listeners. Digital recordings were transferred to personal computer via Firewire (IEEE 1394) interface. Video recordings were edited using Adobe Premiere 6.0 (computer software) for Macintosh. Editing involved creating separate digital video (DV) files for each stimulus sentence produced by each speaker (40 sentences per speaker—20 predictable; 20 unpredictable). Audio samples from DAT were similarly digitized and edited into individual sentences. Audio samples were normalized so that peak output could be calibrated for presentation to listeners. Peak amplitude normalization (via Sound Forge 4.1 computer software) was used to ensure that maximum loudness levels of the recorded speech samples were the same across speakers and sentences while also preserving the amplitude contours of the original productions.

Following procedures described elsewhere (Hustad et al., 2003; Hustad & Cahill, 2003; Hustad, Auker, Natale, & Carlson, 2003), high-quality normalized audio recordings from DAT were associated with DV files, and the native lower-quality audio samples associated with the video were deleted. This was accomplished using Adobe Premiere to visually align the two waveforms (original from DV camera and higher quality from DAT) and auditory–perceptual judgments to confirm that the samples were synchronized.

After digitizing and editing all sentences, all video files were copied, and a second set of samples was created. On the second set of samples, the first letter of each word was experimentally superimposed on the video display. All alphabet cues were placed to the right of the speaker's face. Each letter was shown for the duration of the word, as determined by visual inspection of the waveform within Adobe Premiere. Procedures for superimposing alphabet cues onto the habitual audio signal followed those described by Hustad and Beukelman (2001, 2002).

Two experimental tasks were created for each of the speakers, one involving alphabet cues (AC) and one involving no cues (NC). For each task, there was an equal representation of predictable and unpredictable sentences. Assignment of predictable and unpredictable sentences to the NC and AC tasks was mutually exclusive, so that each sentence occurred in only one task. Further, predictable and unpredictable sentences were sequenced quasi-randomly so that there were never more than three sentences of either type presented adjacent to one another.

To guard against potential order effects, two different tapes were created for each of the two experimental tasks per speaker. The two tapes differed in the order in which sentences were presented. Also, on the second set of tapes, sentences were assigned to the opposite task (NC or AC) to which they were assigned in the first set of tapes. Half of the listeners for each speaker viewed the first set of tapes, and half viewed the second set of tapes.

Experimental task. Listeners viewed the broadcast-quality digital videotapes individually in a sound-attenuating room. During the experiment, listeners were seated at a desk and were positioned approximately 3 ft away from a 27-in television monitor with one external speaker and a digital videocassette player attached to it. The peak output level of stimulus material was approximately 70 dB SPL from where listeners were seated and was measured periodically to ensure that all listeners heard stimuli at the same output level.

The experimenter explained to listeners that they would complete two different tasks, one where a person with cerebral palsy is talking, and one where the first letter of each word is displayed at the same time that the person is talking. They were told that in each task, the speaker would produce a different set of sentences. Following each sentence, there would be a break for the listener to write down what he or she thought the speaker said. For the NC task, listeners were simply told to watch and listen. For the AC task, listeners were instructed that they would see letters on the video screen that corresponded to the words that the speaker was producing. They were encouraged to try to use the letters to help them understand the speaker. For both tasks, listeners were told that they could take as much time as necessary to write their response. They were also told that all sentences would consist of real words, but they were not informed that half of the sentences would be semantically unpredictable. Finally, listeners were advised that the speaker would be difficult to understand and to take their best guess if they were unsure.

Randomization and counterbalancing. To prevent an order effect and/or a learning effect, the order of presentation of the AC and NC tasks was counterbalanced. Thus, half of the listeners for each speaker completed the NC task first, and half completed the AC task first.

Scoring and Reliability

Listener-generated orthographic transcriptions of speakers with dysarthria were evaluated by counting the number of words that were an exact phonemic match to the target words in each utterance produced by the speakers. This paradigm employed standard procedures used in other transcription intelligibility studies (see Garcia and Dagenais, 1998; Hustad et al., 2003). Misspellings and homonyms were accepted as correct, as long as all phonemes in the spoken version of the transcribed word matched the target word. The presence of morphologic errors—affecting, for example, tense and number—rendered the word in which the error occurred incorrect. The number of words identified correctly was tallied and divided by the number of words possible for each listener. This value was used for intelligibility analyses.

Reliability analyses were conducted to ensure the accuracy of the scoring of listener transcripts. To do this, all transcripts were scored a second time using a customized computer program that was under development at the time of initial scoring of the transcripts. Results, obtained by calculating the number of word-level agreements divided by the number of agreements + disagreements, showed 100% consistency between the hand-scored transcripts and the computer-scored transcripts.

Experimental Design and Statistical Procedures

This study employed a 2 × 2 × 8 split plot experimental design (Kirk, 1995). Two variables were repeated measures, and one was a between-subjects measure. The first repeated measure was cues, and its two categories were alphabet cues and no cues. The second repeated measure was predictability, and its two categories were predictable and unpredictable sentences. The between-subjects measure was speaker–group, with each of the 8 speakers having a different group of 16 listeners.

Research questions of interest focused on group data and were specified a priori. Therefore, a planned contrast approach to analysis of variance (ANOVA) was employed in which only the contrasts of interest (collapsed across speakers) were tested (Hertzog & Rovine, 1985; Kirk, 1995; Marascuilo & Levin, 1983; Marascuilo & Serlin, 1988; Seaman, Levin, & Serlin, 1991). This approach is considered more conservative than a traditional full-model ANOVA. Ultimately, this reduces the number of statistical tests and the associated probability of type I error. Alpha was partitioned among the three a priori contrasts using the Bonferroni procedure. Contrasts with a probability less than or equal to .0033 were considered significant (.01/3).

Stepwise regression procedures were performed to characterize how variance in difference scores was associated with different sources. The purpose for this analysis was primarily descriptive; however, tests of significance are also reported.

Results

Effects of Semantic Predictability on Intelligibility

Descriptive statistics showed that mean intelligibility for highly predictable sentences in the no cues condition (NCHP) was 47.82% (*SD* = 24.04). Mean intelligibility for semantically unpredictable sentences in the no cues condition (NCUP) was 33.06% (*SD* = 19.19). These data are displayed graphically in Figure 1. Data for individual speakers are shown in Figure 2.

To test the effects of semantic predictability on intelligibility, one a priori contrast was examined. Results showed that the mean difference in intelligibility between NCUP and NCHP was significant, with NCHP resulting in intelligibility that was 14.76% higher than NCUP sentences. Inferential statistics are shown in Table 2.

Effects of Alphabet Cues on Intelligibility

Descriptive statistics showed that mean intelligibility for semantically unpredictable sentences in the alphabet cues condition (ACUP) was 43.13% (*SD* = 20.42). Again, mean intelligibility for the NCUP condition was 33.06% (*SD* = 19.19).

To test the effects of alphabet cues on intelligibility, one a priori contrast was examined. Results showed that the mean difference in intelligibility between ACUP and NCUP was significant, with ACUP resulting in mean intelligibility that was 10.06% higher than NCUP sentences.

Joint Effects of Semantic Predictability and Alphabet Cues on Intelligibility

Descriptive statistics showed that mean intelligibility for highly predictable sentences in the alphabet cues condition (ACHP) was 58.31% (*SD* = 22.75). Again, mean intelligibility for the NCUP condition was 33.06% (*SD* = 19.19).

To test the joint effects of alphabet cues and semantic predictability on intelligibility, one a priori contrast was examined. Results showed that the mean intelligibility difference between ACHP and NCUP was significant, with ACHP resulting in mean intelligibility that was 25.25% higher than NCUP sentences.

Regression of the Effects of Semantic Predictability and Alphabet Cues Onto Overall Intelligibility Gains

To examine the overall gain in intelligibility scores associated with both semantic predictability and alphabet

Figure 1. Intelligibility by listening condition. NCUP = no cues with unpredictable sentences; ACUP = alphabet cues with unpredictable sentences; NCHP = no cues with highly predictable sentences; ACHP = alphabet cues with highly predictable sentences. Error bars represent +1 *SD* of listener performance.

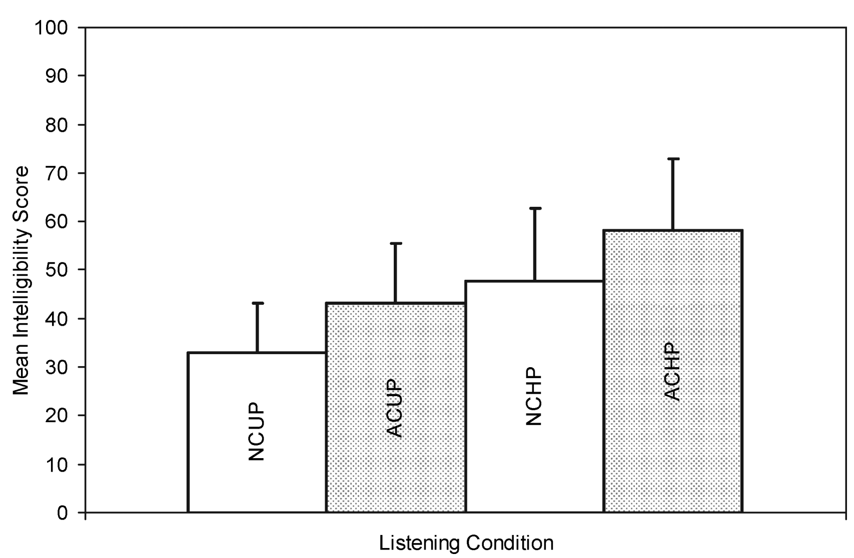
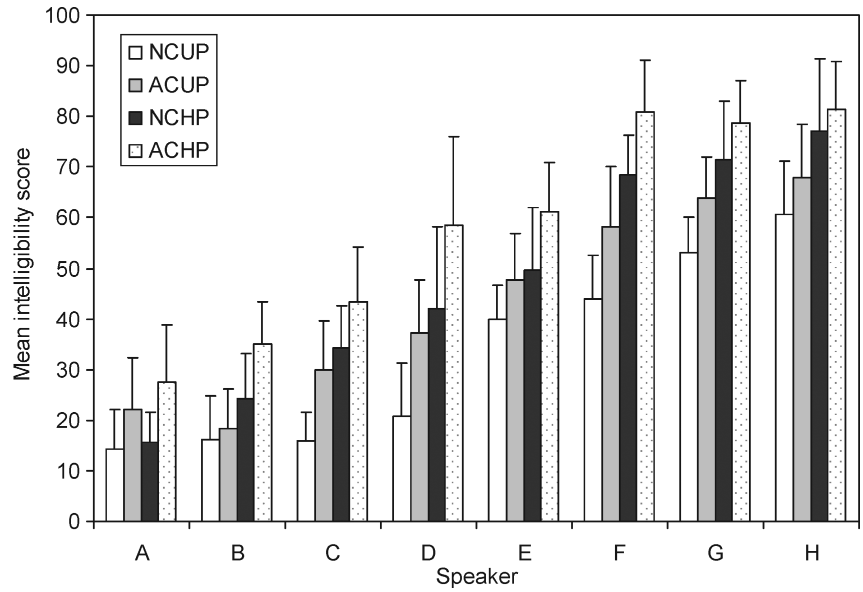


Figure 2. Intelligibility by individual speaker and listening condition. Error bars represent +1 *SD* of listener performance.



cues, difference values were calculated by subtracting NCUP scores from ACHP scores. This overall gain value was the dependent variable in the stepwise regression equation. Independent variables were (a) the gain associated with semantic predictability alone, as calculated by subtracting NCUP from NCHP scores, and (b) the gain associated with alphabet cues alone, as calculated by subtracting ACUP from NCUP scores. It is important to note that all regression procedures were performed using only these three sets of difference scores. Two statistical models were examined. The first model was alphabet cues alone because it had the highest correlation with the overall gain scores. The second model was alphabet cues + semantic predictability.

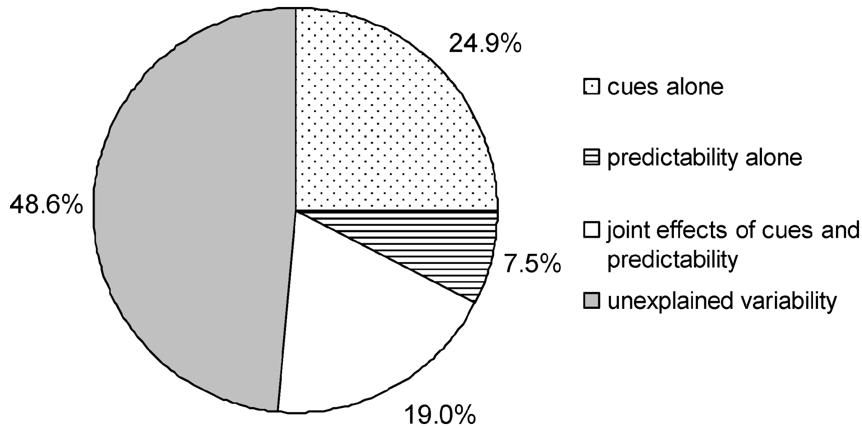
Pearson product–moment correlation coefficients examining relationships among each of the three measures of interest were as follows: overall gain and semantic predictability = .52; overall gain and alphabet cues = .66; semantic predictability and alphabet cues = .40. Each of these correlations was statistically significant ($p < .0001$). The R^2 value with only alphabet cues in the equation was .44 ($p < .001$), indicating that 44% of the variance was accounted for by alphabet cues and any overlapping variance with semantic predictability. When semantic predictability was entered into the equation, R^2 change was .075 ($p < .001$), indicating that an additional 7.5% of the variance was accounted for by semantic predictability. Examination of squared part correlations revealed

Table 2. A priori contrasts examining the effects of semantic predictability and alphabet cues on intelligibility of speakers with dysarthria.

Contrast	Mean difference	*df*	*SE*	*t*	Observed *p* value
Semantic predictability					
NCHP vs. NCUP	14.761	127	1.073	13.752	.0001
Alphabet cues					
ACUP vs. NCUP	15.183	127	.987	15.375	.0001
Semantic predictability and alphabet cues					
ACHP vs. NCUP	25.248	127	1.299	19.427	.0001

Note. NCHP = no cues with high predictability sentences; NCUP = no cues with unpredictable sentences; ACUP = alphabet cues with unpredictable sentences; ACHP = alphabet cues with high predictability sentences.

Figure 3. Percent of variance in overall intelligibility gain explained by the relationship with semantic predictability, alphabet cues, and overlapping effects for speakers with dysarthria.



that the shared variance between semantic predictability and alphabet cues was .19; thus, 19% of the variance was accounted for by joint or overlapping effects of the two sources of knowledge. In addition, the variance accounted for by alphabet cues alone was .25; thus, 25% of the variance was accounted for by the independent contribution of alphabet cues. Finally, the variance that was unaccounted for was .48; thus, 48% of the variance could not be attributed to any of the variables examined in this study. Results are displayed graphically in Figure 3.

Discussion

This study examined the effects of two different sources of signal-independent information on intelligibility of speakers with dysarthria secondary to cerebral palsy. Of particular interest was (a) the independent effect of semantic predictability as determined by comparison of intelligibility scores on highly predictable sentences versus unpredictable sentences; (b) the independent effect of alphabet cues as determined by comparison of intelligibility scores on unpredictable sentences with alphabet cues superimposed versus unpredictable sentences without alphabet cues superimposed; and (c) the joint effect of semantic predictability and alphabet cues as determined by the comparison of intelligibility scores on highly predictable sentences with alphabet cues superimposed versus unpredictable sentences without alphabet cues. Finally, this study examined the extent to which alphabet cues and semantic predictability accounted for the variability in intelligibility gains when both sources of knowledge were available. This discussion focuses on interpretation of findings and clinical implications for each of these questions.

Effects of Semantic Predictability on Intelligibility

Results showed that semantically predictable sentences were nearly 15% more intelligible than semantically unpredictable sentences for listeners of speakers with dysarthria, demonstrating that semantic predictability has a significant effect on intelligibility. This result was not surprising, given the findings of previous studies examining the influence of sentence predictiveness (see Boothroyd & Nittrouer, 1988; Duffy & Giolas, 1974; Garcia & Cannito, 1996; Kalikow et al., 1977).

Descriptive data for individual speakers, provided in Figure 2 and Table 3, showed that there was some variability among speakers, with most difference scores ranging between 8% and 24%. Generally, descriptive differences seemed to be slightly larger for speakers who were less severely involved than for speakers who were more severely involved (see Table 3). This observation suggests that the benefits of semantic predictability were

Table 3. Mean differences (+1 *SD*) in intelligibility scores for semantic predictability and alphabet cues for individual speakers with dysarthria.

	Mean descriptive difference		
Speaker	NCHP vs. NCUP	ACUP vs. NCUP	ACHP vs. NCUP
A	1.13 (6.46)	7.71 (10.25)	13.02 (10.79)
B	8.01 (6.83)	1.98 (9.02)	18.85 (11.32)
C	18.26 (7.63)	13.85 (9.14)	27.42 (13.06)
D	21.46 (9.70)	16.46 (10.45)	37.96 (14.75)
E	9.67 (12.19)	7.71 (11.53)	21.17 (13.65)
F	24.53 (11.60)	14.37 (11.30)	37.08 (12.18)
G	18.44 (10.23)	10.94 (13.15)	25.63 (11.88)
H	16.58 (12.81)	7.50 (13.17)	20.84 (12.37)

limited to some extent by the intelligibility of individual words. Research should investigate whether there may be an intelligibility threshold that is necessary for listeners to benefit from semantic predictability.

Effects of Alphabet Cues on Intelligibility

In the present study, semantically unpredictable sentences with alphabet cues superimposed were approximately 10% more intelligible than semantically unpredictable sentences without alphabet cues for listeners of speakers with dysarthria. This finding demonstrates that alphabet cues had a significant and independent effect on intelligibility. Results were consistent with previous research (Hustad & Beukelman, 2001), which showed that sentence intelligibility scores for 4 speakers with severe dysarthria increased by an average of 18% when alphabet cues were superimposed on habitual speech. One reason for the smaller magnitude of gain in the present study likely relates to the semantic implausibility of the sentence stimuli, which resulted in a cleaner test of the effects of alphabet cues because listeners were unable to apply their semantic knowledge in the intelligibility task. In the Hustad and Beukelman (2001) study, sentences were predictable in nature, so the findings represented the joint benefits of semantic predictability and alphabet cues.

Examination of descriptive results for individual speakers, shown in Figure 3, suggests that there was variability among speakers with regard to the effects of alphabet cues on intelligibility of unpredictable sentences. Most differences ranged between 7% and 16%, although 1 speaker showed a markedly smaller magnitude of benefit than the others—less than 2% gain from alphabet cues. Because a primary purpose of alphabet cues is to provide additional information to reduce lexical uncertainty, it might be expected that cues would be most useful for listeners of speakers whose intelligibility was worse than for listeners of speakers whose intelligibility was relatively better. In the latter case, listeners face less phonetic uncertainty and, therefore, cues would be less likely to provide new information; as a result, intelligibility gains might be expected to be smaller. However, descriptive findings of the present study did not support this assertion. In general, the magnitude of gain from alphabet cues did not seem to differ based on severity of dysarthria. Additional research examining speakers who span a broader continuum of intelligibility levels is needed to determine how severity (particularly speakers who are mildly involved) may influence the usefulness of alphabet cues.

Joint Effects of Semantic Predictability and Alphabet Cues

Finally, and perhaps obviously, results of this study showed that semantically predictable sentences with alphabet cues superimposed were more intelligible than semantically unpredictable sentences without alphabet cues for listeners of speakers with dysarthria. The magnitude of the combined impact of the two types of knowledge was approximately 25%, indicating that listeners use both types of information to their advantage when presented with degraded speech.

Descriptive differences for individual speakers, again, reflected some variability, ranging between approximately 13% and 37% across speakers. As with alphabet cues, descriptive differences for individual speakers did not seem to be influenced by severity of intelligibility deficits. Mean gains for semantic predictability, alphabet cues, and the joint effect of semantic predictability and alphabet cues seem to indicate that for some (but not all) individual speakers and their listeners, the two sources of information may have had a simple additive effect on intelligibility. This finding is consistent with other studies examining the influence of supplemental cues on intelligibility (Hustad & Garcia, 2005; Hustad et al., 2003) and is further addressed through regression analyses.

Partitioning the Effects of Semantic Predictability and Alphabet Cues on Intelligibility Gains

Several interesting findings emerged from the regression analysis in which overall gain scores were partitioned among sources. Alphabet cues accounted for more variance (25%) than semantic predictability (7.5%), suggesting more complexity than an additive model would imply. One potential reason for the greater benefit from alphabet cues relates to the nature and specificity of the information provided by the cues—that is, alphabet cues provided information regarding initial phonemes of words (via orthography) and word boundaries (via the duration of the letter cues), both of which were specific, explicit, and directly relevant to the task of resolving lexical ambiguity to transcribe sentences.

Also noteworthy was the inseparable joint influence of semantic predictability and alphabet cues, which made a contribution to explaining the variance in gain scores (19%) that was similar in magnitude to alphabet cues—that is, when both sources of information were available, they acted to enhance intelligibility in a unique way that could not be attributed to either source alone. This finding lends support to Hustad and Beukelman's (2001) speculation that alphabet cues may interact with or enhance the usefulness of linguistic knowledge. However, the specific manner in which this occurs is unknown. One possibility is that alphabet cues may have served as an important source of information for resolving lexical uncertainty to some minimal level. Once listeners reached this point, they may have been able to use semantic predictability more effectively.

Although slightly more than half of the variance in gain scores was accounted for by semantic predictability, alphabet cues, and joint sources of information, almost half of the variance in gain scores was unexplained. This indicates that other variables not examined in the present study had an important influence on listener performance. Examination of Figure 1 shows that the standard deviations for each speaker were large for all of the experimental conditions. Listener-related candidate variables that may play a role in this variability include perceptual tuning or learning that occurs over the course of an experiment, effort, self-efficacy, and motivation. Variables related to the speaker also likely influence listeners' success. Speaker-related candidate variables include severity of the speech impairment, subsystem involvement and characteristics, and spectral and temporal acoustic characteristics of the speech signal.

Recently, Klasner and Yorkston (2005) developed measures to describe barriers and strategies to intelligibility for listeners of speakers with amyotrophic lateral sclerosis and Huntington's disease. Although they did not quantify production characteristics beyond perceptual features of speech, their research suggested that dysarthria type may influence both barriers to intelligibility and listening strategies. Examination of barriers and strategies that listeners use for speakers with cerebral palsy along with a description of acoustic features of speech may be one way to begin mapping perceptual strategies onto production characteristics in order to identify different sources of variability in intelligibility scores. Research is needed in this area.

Clinical Implications

The present study highlights the importance of the listener in speech intelligibility. Indeed, intelligibility of the same speakers was markedly altered based on the semantic content of utterances and based on presentation of experimentally superimposed alphabet cues, both in the absence of any production modifications by the speakers. In general, findings were consistent with other research, demonstrating that semantic predictability and alphabet cues were both powerful sources of information that enhance intelligibility. However, this study extended previous work through the finding that these two sources of information made mutually exclusive as well as overlapping contributions to intelligibility gains, with alphabet cues being a more powerful source of information than semantic predictability.

Interventionists agree that communication partners should be involved in speech therapy for individuals with dysarthria (Yorkston et al., 1999). Findings related to the significant impact of semantic predictability raise the possibility that perhaps interventions aimed at helping communication partners use their semantic knowledge could increase communicative success for speakers with dysarthria. Similarly, interventions aimed at teaching speakers how to construct messages that capitalize on listener's semantic knowledge would likely have equal promise.

With regard to the effects of alphabet cues, generalization to clinical contexts is difficult because the cues were experimentally superimposed on habitual speech in the present study. This study demonstrated, however, that listeners were able to make use of alphabet cues even when these cues were presented for short durations and in rapid succession. In some sense, findings present a "worst-case scenario" regarding the effects of alphabet cues. When cues are actually implemented by speakers, rate of speech tends to decrease, with longer pauses between words (Hustad & Garcia, 2005; Hustad et al., 2003), so listeners benefit from the effects of pauses between words, increased processing time, and the alphabet cues themselves. Consequently, the magnitude of benefit from alphabet cues would likely be larger when speakers actually implement the strategy. However, further research is necessary to understand the myriad of variables that affect speech intelligibility.

Limitations and Future Directions

The present study explored a clinical topic using a highly controlled and contrived experimental paradigm. As such, there are a number of important limitations related to the speech stimuli, the speaking context, and the listening task, none of which reflect communicative interaction in any sort of real circumstance. Studies that examine ecologically valid communication situations are needed to gather information about the spontaneous language that speakers use and listeners' ability to employ different sources of information in more natural contexts.

From this study, and previous ones, it is clear that intelligibility of dysarthric speech is influenced by a variety of variables related to both the speaker and the listener. Future studies should examine the influence of other sources of information on intelligibility of dysarthric speech—for example syllable shape and complexity, syntactic complexity, utterance length, and prosodic contour. Understanding how these sources of information impact listener performance will further our knowledge base regarding potential avenues for enhancing intelligibility. From there, interventions that capitalize on important sources of information can be developed and validated for speakers with dysarthria and their listeners.

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Appendix. Examples of semantically anomalous sentences and predictable sentences.

Examples of semantically anomalous sentences (Nye & Gaitenby, 1974)	Examples of predictable sentences (Hustad & Beukelman, 2001, 2002)
The wrong shot led the farm	He wanted a new car
The short arm sent the cow	Jason liked the large pickup trucks
The salt dog caused the shoe	On July fourth, most people celebrate
The chance sun laid the year	Some towns have local parades
The near stone thought the ear	Some towns host a public cookout
The fine lip tired the earth	Jeffrey and Jacob are sports fanatics
The clean book reached the ship	They had a tailgate party first
The far man tried the wood	This spring the weather was horrible
The dry door paid the race	The river rose above its bank
The hot nest gave the street	The town was a disaster