Clinical Linguistics & Phonetics, May 2007; 21(5): 353–367

Effects of visual information on intelligibility of open and closed class words in predictable sentences produced by speakers with dysarthria

KATHERINE C. HUSTAD, CAITLIN M. DARDIS, & KELLY A. MCCOURT

Department of Communicative Disorders & Waisman Center, University of Wisconsin-Madison, WI, USA

(Received 14 December 2006; accepted 1 February 2007)

Abstract
This study examined the independent and interactive effects of visual information and linguistic class of words on intelligibility of dysarthric speech. Seven speakers with dysarthria participated in the study, along with 224 listeners who transcribed speech samples in audiovisual (AV) or audio-only (AO) listening conditions. Orthographic transcriptions from listeners were scored for the number of words identified correctly. Correctly identified words were then coded into two linguistic classes, open and closed. Results showed that across all speakers and listeners, the AV presentation mode resulted in significantly higher intelligibility scores than the AO mode. However, the difference was significant for only three of seven individual speakers. Results also showed that across all speakers and listeners, closed class words were more intelligible than open class words. The difference between linguistic classes was significant for six of seven individual speakers. The interaction between linguistic class and mode of presentation was not significant, indicating that the margin of benefit for closed class words was consistent across presentation modalities.

Keywords: *Dysarthria, intelligibility, visual information, open class words, closed class words*

Introduction

Intelligibility is a dyadic phenomenon that refers broadly to a listener's ability to decipher spoken messages produced by a speaker. Many factors contribute to speech intelligibility, including variables related to production of the signal (speaker variables) and variables related to perception of the signal (listener variables). Hustad and Weismer (2007) suggest that intelligibility should be a primary concern to interventionists working with speakers who have dysarthria. Thus, the understanding of variables that influence intelligibility has important clinical relevance.

In this paper, we examine the effects on intelligibility of visual information and linguistic class of words produced by speakers with dysarthria. The listener perception vantage point was of particular interest; therefore, the focus of this study was on manipulating and

Correspondence: Katherine C. Hustad, 1500 Highland Avenue, Room 475, Madison, WI 53705, USA. Tel: +1 608 265 9977. E-mail: kchustad@wisc.edu

ISSN 0269-9206 print/ISSN 1464-5076 online
DOI: 10.1080/02699200701259150

measuring whether the presence of visual information affected listeners' transcription accuracy, and whether listeners were able to transcribe words from open and closed linguistic classes with different levels of accuracy. Literature addressing each of these areas is reviewed below.

Influence of visual information on intelligibility

Studies examining the influence of visual-facial information from non-motor impaired speakers have consistently shown that when listeners can see and hear speakers, intelligibility is higher than when listeners can only hear speakers. For example, research has shown that frequency filtered speech (Sanders & Goodrich, 1971), speech degraded by noise (O'Neill, 1957; Neely, 1956), hearing impaired speech (Erber, 1975; Monsen, 1983) and esophageal speech (Berry & Knight, 1975; Hubbard & Kushner, 1980) all tend to be more intelligible when listeners can see the speaker while he or she is talking. These findings are not surprising given that visual cues are thought to provide listeners with an additional source of information that reinforces or adds redundancy to the acoustic signal (Erber, 1975).

By definition, speakers with dysarthria have problems with motor control of the speech musculature, which typically result in a compromised acoustic signal (Duffy, 2005). Speech motor control problems often lead to movement characteristics that are quantitatively and qualitatively different (Kent & Adams, 1989) than those of neurologically in-tact speakers. Consequently, visual-facial information from speakers with dysarthria may not always be consistent with listener expectations and may even mislead listeners as they try to interpret a spoken message. Although research is somewhat limited, the collective body of studies examining intelligibility of speakers with dysarthria suggests that the impact of visual information is variable. One important issue may be the extent to which all facial musculature is affected by the dysarthria. This question has not been systematically addressed in the literature and descriptions of participants and their motor involvement in published studies of intelligibility vary in their level of detail.

Another important factor that seems to play a role in whether visual information enhances intelligibility is severity of dysarthria. Although severity is a fairly straightforward concept, it can be defined and characterized in a number of different ways. For the purposes of the present study, we operationalize severity on the basis of transcription intelligibility scores (see Weismer & Martin, 1992). A summary of findings from published studies, organized by severity of individual speakers within each study (based on our own severity designations per the reported transcription intelligibility scores), is presented in Table I. Studies suggest that listeners of speakers with moderate dysarthria (defined for our purposes as 50−75% intelligibility) seem to benefit most from the provision of visual information, with typical gains of approximately 10−20% (see Hunter, Pring, & Martin, 1991; Keintz, Bunton, & Hoit, in press; Garcia & Dagenais, 1998).

Studies also seem to suggest that intelligibility gains for listeners of speakers with mild dysarthria (defined for our purposes as above 75% intelligibility) are nominal (less than 5%) when visual information is presented with the auditory signal (Hustad & Cahill, 2003; Keintz et al., in press). One exception is the finding of Garcia and Dagenais (1998) for one speaker with mild dysarthria who showed an 11% gain from the presence of visual information.

Research examining speakers with severe (defined for our purposes as 25−49% intelligibility) and profound (defined for our purposes as below 25% intelligibility)

Table I. Summary of published studies examining the difference between audio-only and audiovisual presentation modes for speakers with dysarthria. Note that severity levels were assigned for this table based upon average intelligibility scores across experimental listening conditions for each study. Intelligibility gains reported are approximate and were inferred from published charts in some cases. PD=Parkinson disease; CP=Cerebral Palsy.

Severity	Study	No. of speakers	Etiology	Approximate intelligibility gain from AV condition
Mild (greater than 75% intelligibility)	Keintz et al. (in press)	4 of 8	PD	4%; 4%; 5%; 5%
	Hustad & Cahill (2003)	2 of 5	CP	2%; 3%
	Garcia & Dagenais (1998)	1 of 4	Stroke	11%
Moderate (50–75% intelligibility)	Hunter, Pring, & Martin (1991)	4 of 8	CP	average gain=17%*
	Keintz et al. (in press)	3 of 8	PD	4%; 16%; 20%
	Garcia & Dagenais (1998)	2 of 4	ALS, Stroke	19%, 9%
Severe (25–49% intelligibility)	Garcia & Cannito (1996)	1 of 1	Stroke	3%
	Hunter et al. (1991)	4 of 8	CP	average gain=−1%*
	Hustad & Garcia (2005)	2 of 3	CP	4%; 4%
	Keintz et al (in press)	1 of 8	PD	16%
	Hustad & Cahill (2003) (Table continues)	3 of 5	CP	−1%; 4%; 10%
Profound (less than 25% intelligibility)	Hustad & Garcia (2005)	1 of 3	CP	2%
	Garcia & Dagenais (1998)	1 of 3	Stroke	8%

* Individual data were not presented in the published paper.

dysarthria have shown greater variability in results with regard to the influence of visual information on intelligibility. For example, Hunter and colleagues found no intelligibility gain for four speakers with cerebral palsy and severe dysarthria for audio-only vs. audiovisual listening conditions. However, Hustad and Cahill found an intelligibility gain of 10% for one speaker with cerebral palsy and severe dysarthria; and Keintz and colleagues found an intelligibility gain of 16% for one speaker with Parkinson's disease and severe dysarthria. Studies examining speakers with profound dysarthria have been fewer in number. One study found that intelligibility increased by 8% for a speaker who had profound dysarthria secondary to stroke (Garcia & Dagenais, 1998) when audiovisual information was provided. Another study found that audiovisual information did not enhance intelligibility for one speaker with cerebral palsy and profound dysarthria (Hustad & Garcia, 2005).

Clearly questions remain regarding the impact of visual information on intelligibility, particularly for speakers with severe and profound dysarthria. The answers to these questions may have important treatment implications, particularly with regard to training partners in the use of listening strategies.

Influence of linguistic class on intelligibility

Another issue of interest for the present study was whether an intelligibility advantage exists for particular types of words. Words within the lexicon vary along a number of important dimensions. Examples include phonetic and syllabic complexity, phonotactic probabilities, density of lexical neighbourhoods, morpho-syntactic characteristics, semantic importance, and frequency of occurrence. There are two general grammatical classes, closed and open, that help differentiate words on the basis of some of the aforementioned dimensions (Cutler, 1993). Closed class words include all conjunctions, prepositions, determiners, pronouns, auxiliary verbs, and particles. Closed class words tend to be comprised of few phonemes and are usually monosyllabic; they occur very frequently in English and are used primarily as markers of syntactic structure, carrying little meaning in and of themselves. Open class words include all nouns, adjectives, adverbs, and "full verbs". Open class words tend to be more complex in their phonetic and syllabic structure; and they play a primary role in conveying semantic content.

When words are produced by a speaker, the acoustic signal contains prosodic variations (i.e. stress, intonation, and duration) that that seem to be perceptually important for lexical segmentation and access (Grosjean & Gee, 1987; Cutler, 1993). Studies have shown that closed and open class words tend to have acoustically distinctive characteristics that may help focus listeners' attention on information-bearing words in the speech signal. For example, open class words tend to have longer vowel durations (Turner & Tjaden, 2000; Pichney, Durlach, & Braida, 1986) and usually contain at least one strong or stressed syllable when produced in sentential context (Cutler, 1993). Researchers argue strongly that this lexical stress is an important factor in speech perception, with words that contain at least one stressed syllable having a perceptual advantage over words that do not contain a stressed syllable (Cutler, 1993; Grosjean & Gee, 1987).

A recent study by Hustad (2006) examined intelligibility of speakers with dysarthria who varied in severity from mild to profound for three different types of words produced within sentences. These were (a) content words, which included all nouns, pronouns, and verbs; (b) modifiers, which included all adjectives and adverbs; and (c) functors, which included all articles, prepositions, and conjunctions. Results showed that modifiers and content words were less intelligible across all speakers and listeners than functor words. The magnitude of this difference ranged from 8–23%. One explanation for this finding was that functor words tend to be simpler in their phonetic and syllabic complexity and more predictable, relative to the other types of words. As a result, they may have been easier for speakers to produce and easier for listeners to perceive in spite of their presumed reduced lexical stress. None the less, this finding was somewhat troubling because it suggested that listeners have difficulty deciphering information-bearing words produced by speakers with dysarthria.

In the present study, our goal was to replicate and extend previous findings using a different, yet related, coding scheme whereby words were coded into two linguistic classes, closed and open. We were also interested in determining if the presence of visual-facial information interacted with intelligibility of closed and open class words.

This study addressed the following specific research questions:

1. Does visual information enhance listener performance in transcribing the speech of individuals with dysarthria? If so, are there individual differences among speakers?
2. Are closed class words easier for listeners of speakers with dysarthria to transcribe than open class words? If so, are there individual differences among speakers?
3. Do presentation modality and linguistic class of words have an interactive effect on intelligibility scores for speakers with dysarthria? If so, are there individual differences among speakers?

Method

Participants

Participants included speakers with dysarthria and "everyday" listeners (Klasner & Yorkston, 2005). Speakers with dysarthria produced speech samples, which were then played for the listeners who orthographically transcribed what they heard. Listener transcription results were the dependent variable of interest.

Speakers with dysarthria. Seven adults who had cerebral palsy participated as speakers. All speakers had dysarthria and reduced intelligibility. Severity of dysarthria varied among the speakers, ranging from mild to severe, as determined by scores on the Sentence Intelligibility Test (SIT) (Yorkston, Beukelman, & Tice, 1996). Table II provides demographic information for the speakers including age, gender, dysarthria diagnosis, dysarthria severity, and SIT score. All speakers were required to: (a) speak American English as their first and primary language; (b) have normal hearing per self report; (c) have

Table II. Characteristics of speakers with dysarthria.

Speaker	Age	Gender	Dysarthria diagnosis	SIT score
1	33	M	Mixed spastic-hyperkinetic	20%
2	33	F	Mixed spastic-ataxic	20%
3	42	F	Spastic	27%
4	55	M	Spastic	75%
5	32	F	Spastic	83%
6	37	M	Spastic	75%
7	34	M	Hyperkinetic	80%

scores between 20% and 85% on the SIT; (d) be able to repeat sentences of up to eight words in length following a verbal model.

Listeners. A total of 224 listeners participated in the experiment. A different group of 16 listeners heard each of the seven speakers in each of the two listening conditions (audio-only (AO), and audiovisual (AV)). All listeners were required to: (a) use American English as their first and primary language; (b) pass a pure tone hearing screening at 20dB SPL for 250Hz, 500Hz, 1kHz, 4kHz, and 6kHz 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 students as well as other individuals who responded to public postings. Listeners had a mean age of 21.5 years (SD=3.2 years). There were 103 male participants and 141 female participants; however, differences between males and females were not examined.

Materials and procedures

Stimulus sentences. As part of a larger study (see Hustad, in press), speakers produced a standard set of speech stimuli, including predictable and unpredictable sentences. The present study focused on productions of 20 different sentences taken from Hustad and Beukelman (2001; 2002). These sentences were designed to be predictable in nature, although predictability was not quantified in the development of the stimuli. Sentences employed standard American English conventions for content, form, and use of language and were five to seven words in length (e.g. They wanted season tickets for next year; Rain caused severe flash floods; It is a national holiday). See Table IV for summary statistics regarding open and closed class words within the sentences.

Recording speakers. Each speaker was audio and video recorded in a quiet environment, either within his or her home or in a sound attenuating room in the laboratory. Speakers wore a low profile unidirectional head mounted microphone positioned 5cm from the mouth. To assure that differences in reading fluency and visual acuity did not influence speech production characteristics, speakers produced all speech stimuli 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 were required to produce each sentence verbatim, including all constituent words. They were asked to repeat any sentence that did not include all words. Speakers were encouraged to speak as naturally as possible.

Preparing speech samples for playback to listeners. Digital video recordings were transferred to personal computer via Firewire (IEEE 1394) interface. Video recordings were edited to create separate digital video (DV) files for each stimulus sentence produced by each speaker. Audio samples from DAT were similarly digitized and edited into individual sentences. Peak amplitude normalization (via Sound Forge 4.5 computer software) was used to assure that maximum loudness levels of the recorded speech stimuli were the same across speakers and sentences, while also preserving the amplitude contours of the original productions.

After digitizing and editing all sentences, two sets of experimental video tapes were created for each speaker using Adobe Premiere Pro. The following information was provided on the video tape: (1) written instructions for the task; (2) sentence number; (3) AV or AO presentation of the target sentence; (4) written instructions to transcribe the preceding sentence. Items 2–4 were repeated until all sentences were completed.

For the tapes containing the AV stimuli, the video image of the speaker producing each target sentence was shown on the tape. For the tapes containing the AO stimuli, a plain blue background was shown on the tape in place of the video image of the speaker. Thus, trial duration, instructions, and pauses were identical for AO and AV conditions.

To guard against potential order effects, two different tapes were created for each of the two experimental tasks. On the two sets of tapes, sentences were presented in a different order. Half of the listeners for each speaker viewed the first set of tapes and half viewed the second set of tapes.

Experimental task. Listeners completed the experimental tasks independently in a sound attenuating room. During the experiment, listeners were seated at a desk and were positioned approximately 3 feet away from a 27-inch television monitor with one external speaker and a digital video cassette player attached to it. The peak output level of stimulus material was approximately 70dB SPL from where listeners were seated and was measured periodically to assure that all listeners heard stimuli at the same output level.

Listeners were told that they would either see or hear a person with cerebral palsy who was saying a list of sentences. Following each sentence, listeners were instructed that there would be a break for them to write down what the speaker said. 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. Finally, listeners were advised that the speaker may be difficult to understand and to take their best guess.

Scoring and reliability

Listener-generated orthographic transcriptions of speakers with dysarthria were scored using an in-house computer program that tallied the number of words that were an exact phonemic match to the target words in each utterance produced by the speakers. Misspellings and homonyms were accepted as correct, as long as all *phonemes* in the spoken version of the transcribed words matched the target words. The number of words identified correctly was summed and divided by the number of words possible for each listener. This value was used for intelligibility analyses.

Listener-generated orthographic transcriptions of speakers with dysarthria were also coded for linguistic class. Words that were orthographically transcribed correctly were separated into two mutually exclusive linguistic categories, open class and closed class. Open class words included all nouns, adjectives, adverbs and "full verbs". Closed class words included all conjunctions, prepositions, determiners, pronouns, auxiliary verbs, and particles. The number of words identified correctly was summed and divided by the number of words possible for each linguistic category for each listener. This value was used to compare differences in transcription accuracy between linguistic categories.

Reliability analyses were conducted to evaluate the accuracy of the scoring and coding of listener transcripts. To do this, one transcript from each condition (AV and AO) for each group of listeners was scored and coded a second time by hand. 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 for intelligibility and coding.

Experimental design and statistical procedures

This study employed a $2 \times 2 \times 7$ split plot experimental design (Kirk, 1995). The repeated measure was linguistic class and its two categories were open and closed class words. The first between subjects measure was presentation condition and its two groups were AV and AO. The second between subjects measure was speaker-group. Sixteen different listeners were randomly assigned to hear each of the seven speakers, in each of the two listening conditions.

Research questions of interest focused on linguistic class data, presentation condition data, and the interaction between linguistic class and presentation conditions. Therefore, only statistical tests pertaining to these three variables were considered, thus reducing the number of statistical tests and the associated probability of type I error. Follow up contrasts for significant effects were performed used the Bonferroni procedure to partition alpha. An alpha level of .05 was allotted to each family of follow-up contrasts.

Results

Presentation conditions

Descriptive statistics, shown in Figure 1, suggest that intelligibility scores were higher across all speakers and within individual speakers for the AV condition than for the AO condition. ANOVA results showed that the main effect of presentation condition was significant ($F(1, 210)=31.771$; $p<.0001$).

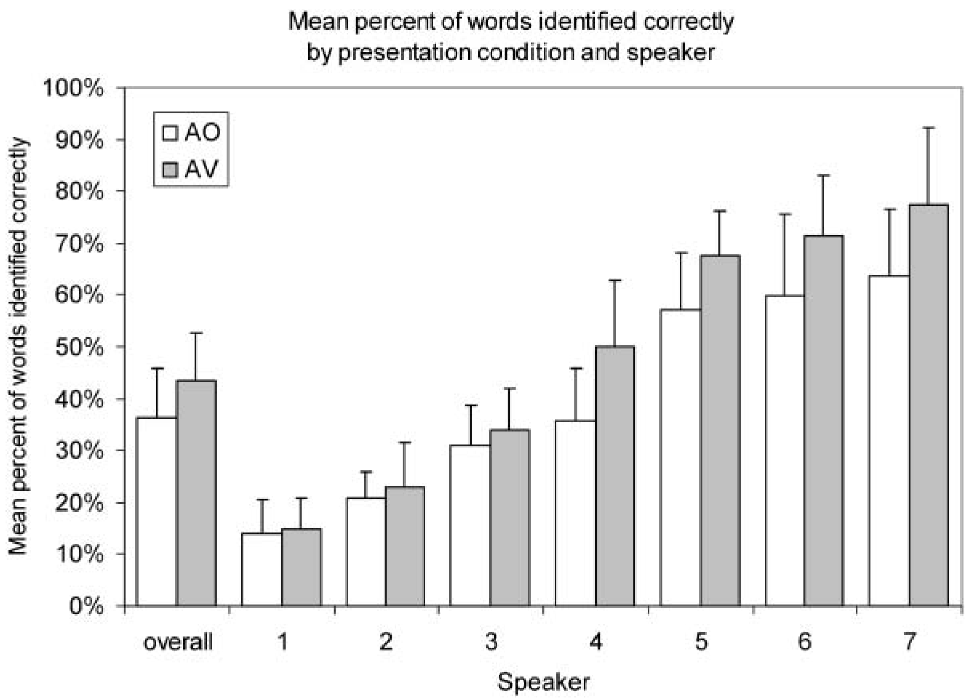

Figure 1. Intelligibility by presentation condition and speaker (AO=audio-only presentation condition; AV=audiovisual presentation condition). Error bars represent +1 standard deviation of listener performance.

Seven independent sample t-tests, with alpha partitioned using the Bonferroni procedure were used to examine follow-up contrasts of interest (Howell, 2002, 2004; Marascuilo & Serlin, 1988). Findings, presented in Table III, showed that the difference between AV and AO presentation conditions was significant for Speakers 4, 5, and 6; but not for Speakers 1, 2, 3, and 7.

Linguistic classes

Descriptive statistics, illustrated in Figure 2, suggest that intelligibility was higher for closed class words than for open class words. This observation was true for mean data across all speakers and for each individual speaker. ANOVA results showed that the main effect of linguistic class was significant ($F(1, 210)=479.93$; $p<.0001$).

Following procedures described above, seven paired sample t-tests were performed to examine follow-up contrasts of interest. Findings, presented in Table III, showed that the difference between open and closed class words was significant for Speakers 1, 2, 3, 5, 6, 7; but not for Speaker 4.

Interaction between presentation condition and linguistic class

Descriptive results (pooled across all speakers and their listeners), illustrated in Figure 3, suggest that the difference in intelligibility scores for closed and open class words was

Table III. Follow-up contrasts comparing differences in intelligibility scores by linguistic class and presentation modality for individual speakers with dysarthria.

Contrast	Mean difference (proportion correct)	df	SE	t	Observed p-value
Speaker 1					
AV vs. AO	.008	30	.022	.370	.714
Open vs. Closed Class	.168	31	.017	9.594	<.001*
Speaker 2					
AV vs. AO	.023	30	.025	.904	.373
Open vs. Closed Class	.259	31	.019	13.157	<.001*
Speaker 3					
AV vs. AO	.028	30	.027	1.030	.311
Open vs. Closed Class	.248	31	.019	12.640	<.001*
Speaker 4					
AV vs. AO	.1439	30	.041	3.534	.001*
Open vs. Closed Class	.0530	31	.029	1.834	.076
Speaker 5					
AV vs. AO	.1052	30	.035	2.963	.006*
Open vs. Closed Class	.1404	31	.019	7.102	<.001*
Speaker 6					
AV vs. AO	.1368	30	.049	2.780	.009*
Open vs. Closed Class	.1378	31	.018	7.495	<.001*
Speaker 7					
AV vs. AO	.1142	30	.049	2.316	.028
Open vs. Closed Class	.1862	31	.019	9.782	<.001*

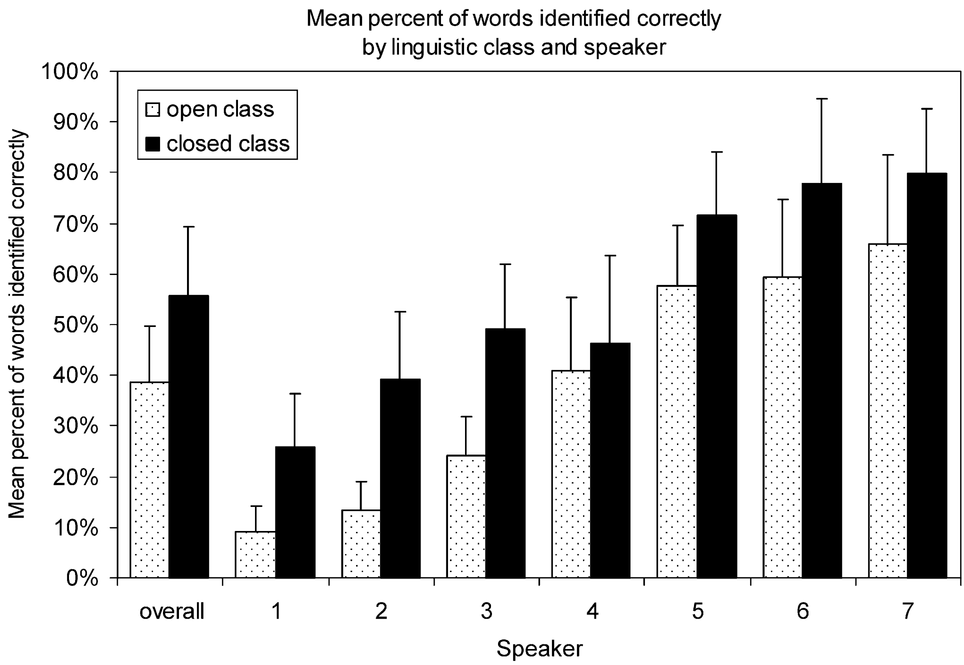

Figure 2. Intelligibility by linguistic class and speaker. Error bars represent +1 standard deviation of listener performance.

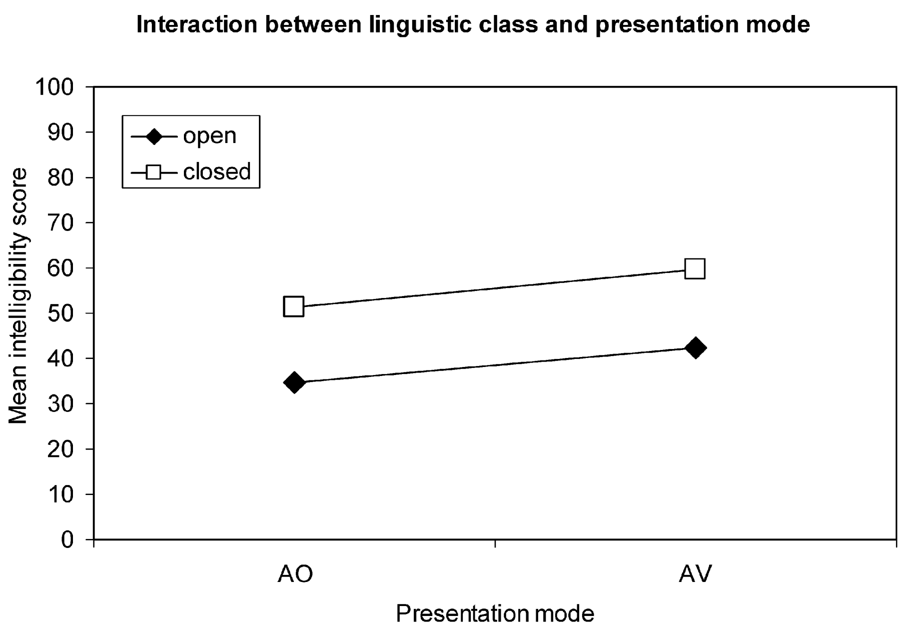

Figure 3. Interaction between linguistic class and presentation modality with data pooled across all speakers and listeners.

constant for the AV and AO condition. ANOVA results showed that the interaction between linguistic class and presentation condition was not significant ($F\ (1, 210=.071)$; $p=.790$). Consequently, no follow-up tests were performed for individual speakers.

Discussion

This study examined the independent and interactive effects of visual information and linguistic class of individual words produced in sentential context on intelligibility of dysarthric speech. Seven speakers with moderate, severe, and profound dysarthria participated in the study, along with 224 listeners who transcribed speech samples in audiovisual or audio-only listening conditions. Orthographic transcriptions from listeners were scored for the number of words identified correctly in the two listening conditions. Correctly identified words were then coded into two linguistic classes, open and closed. Results showed that across all speakers and listeners, the AV presentation mode resulted in significantly higher intelligibility scores than the AO mode (approximately 7% difference). However, within individual speakers, the difference between AV and AO conditions was significant for only three of seven speakers. Results also showed that across all speakers and listeners, closed class words were significantly more intelligible than open class words (approximately 17% difference). Within individual speakers, the difference between linguistic classes was significant for six of seven speakers. The interaction between linguistic class and mode of presentation was not significant; thus, the magnitude of the intelligibility difference between open and closed class words was constant for the AV and AO presentation modes. Results are discussed in detail below.

Effects of audiovisual information on intelligibility

Results of this study were consistent with previous literature, demonstrating that mean intelligibility scores across speakers and listeners were increased when audiovisual information was presented to listeners (Hustad & Cahill, 2003; Keintz et al., in press). Within individual speakers, this finding was not universally true; and listeners of speakers who had moderate dysarthria tended to show larger gains from the presence of visual information than did listeners of speakers who had profound dysarthria. Indeed, a simple post hoc analysis in which mean intelligibility scores (across AV and AO conditions) were correlated with difference scores between AV and AO conditions confirmed that a strong linear correlation was present ($r=.85$), indicating that as difference scores between conditions increased, mean intelligibility also increased.

For the three speakers with moderate dysarthria (Speakers 5, 6, and 7), intelligibility scores increased by 10%, 14%, and 11%, respectively, when visual information was provided. It is noteworthy that there was considerable variability in listener performance. As a result, gains for Speaker 7 were not statistically significant. Overall, however, results from the current study were consistent with other studies examining speakers who had moderate dysarthria (see Hunter et al., 1991; Keintz et al., in press; Garcia & Dagenais, 1998). It, therefore, seems reasonable to conclude that listeners of speakers with moderate dysarthria may benefit more than any other severity group from the availability of visual information.

For the two speakers with severe dysarthria (Speakers 3 and 4), intelligibility gains varied, with one speaker showing a 3% increase and the other showing a 14% increase. It is interesting to note that the speaker who showed the larger gain (Speaker 4) was also more intelligible, on average, than the other speaker. In general, these findings were consistent with previous literature (see Hustad & Cahill, 2003), which showed variability among speakers with severe dysarthria in the benefit from visual information.

Finally, the two speakers with profound dysarthria (Speakers 1 and 2), both showed little or no change in intelligibility from the provision of visual information. This finding is, again, consistent with previous literature examining speakers with cerebral palsy (Hustad & Garcia, 2005). Overall, results of this study suggest that there may be a minimal intelligibility level that must be attained before visual information has a meaningful impact on intelligibility of dysarthric speech.

Effects of linguistic class on intelligibility

Results of this study were consistent with previous work examining intelligibility of words from different linguistic classes produced by speakers with dysarthria (see Hustad, 2006). Overall, results showed that closed class words were more intelligible than open class words by about 17%. This difference was significant for all but one speaker, with magnitudes ranging between 14% and 26% among speakers for whom the difference was significant. The difference between intelligibility of closed and open class words was somewhat larger on average than that observed by Hustad (2006). One reason may be related to the way in which words classes were divided. In the previous study, three word classes were examined (content words, modifiers, and functor words) and some closed class words, albeit few, were counted within each of the three classes, potentially inflating intelligibility scores for content words and modifiers. In the present study, only two classes were examined.

Closed class words are almost always unstressed in non-disordered habitual speech (Cutler, 1993). Lexical access research suggests that words containing stressed syllables may be easier to decipher than words that do not contain stressed syllables for a variety of reasons. In the present study, this was not the case. However, there are a number of potential reasons that open class words were less intelligible than closed class words. First, closed class words tend to be simpler, both phonemically and syllabically than open class words. This makes them easier to produce, which potentially increases the likelihood that speakers with dysarthria will say them accurately. Research has shown that speakers with cerebral palsy tend to have difficulty producing word-final consonants (Platt, Andrews, & Howie, 1980), which may be especially detrimental to listeners' ability to distinguish among longer open-class lexical competitors. In addition, closed class words occur much more frequently in the English language, thus they are likely to be more predictable than many open class words (see Table IV).

Table IV. Characteristics of open and closed class words within sentences produced by speakers with dysarthria. Note that data are from 20 different sentences used in this study.

	Closed Class Words	Open Class Words
Total number of words	40.00	77.00
Number of different words	22.00	72.00
Average number of phonemes	2.25	4.64
Average number of syllables	1.02	1.63
Written word frequency*	20048.75	313.02

* from Kucera, H. & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

In summary, the finding that open class content words are more difficult for listeners to perceive is unfortunate for speakers with dysarthria and their listeners. There is clearly a need for development of intervention strategies that facilitate improvement in production and perception of open class content words produced by speakers with dysarthria.

Interaction between linguistic class and presentation modality

Results of this study showed that there was not a significant interaction between intelligibility of words from open and closed classes and presentation modality. In essence, this means that although on average the AV mode resulted in higher intelligibility scores than the AO mode, the margin of benefit for closed class over open class words was the same for the AV and AO modes (approximately 17%). The finding that the AV mode did not provide a differential advantage for either linguistic class indicates that the higher intelligibility scores observed for closed class words was robust and not easily influenced by other factors.

Limitations and future directions

There are several limitations to the present study. Specifically, a small number of speakers with dysarthria were included; although they all had cerebral palsy, speakers varied in several important ways including severity of impairment and type of dysarthria. Additional research that systematically examines speakers with different types of dysarthria from different aetiologies is necessary to further validate findings of the present study.

This study used an experimental paradigm in which speakers produced scripted sentences. Acoustic analyses were not performed on sentences produced by speakers, so the supposition that closed class words were in fact unstressed was not actually tested. Rather, this was assumed to be true based on other literature. Because sentences were scripted, other facial cues and gestures that signal emotion and emphasis were likely not present. This may have biased results to some extent. Studies using spontaneous speech produced in different contexts (i.e. narration and conversation) should examine the extent to which the communicative purpose may affect intelligibility in different presentation modes and intelligibility of open and closed-class words. In addition, studies should examine speakers' use of stress for open and closed class words. Perhaps some speakers with dysarthria use inappropriate stress on closed class words, which may provide an additional explanation for the findings of the present study.

Listeners made transcriptions of speakers' productions under highly controlled listening conditions. They did not receive feedback on their performance and they were not able to engage in real communicative exchanges with speakers. These factors may have played an important role in the types of words that listeners were able to decipher. Studies that examine the influence of linguistic class and visual information, among other variables, in a variety of listening and speaking conditions are necessary to fully understand the role these variables play in communication.

Clinical implications

Results of the present study showed that, on average, visual information enhanced intelligibility for listeners of speakers with dysarthria, and gains associated with visual information were similar for open and closed class words. However, listeners of speakers with moderate dysarthria showed the greatest overall benefit from the availability of visual information. There are several important clinical implications related to these findings. For example, it may be worthwhile to pursue the development of treatment strategies for speakers with moderate dysarthria that maximize visual-facial cues. This type of intervention may involve training listeners in how to use visual-facial information, and potentially on training speakers to emphasize visible speech-related movements while talking.

A disconcerting finding of this study was that listeners were able to decipher closed-class words more easily than open-class words, regardless of presentation modality. Although there are several plausible explanations for this (e.g. phonetic and syllabic complexity, word frequency, predictability), the end result is not good—listeners have more difficulty deciphering important content bearing words than they do closed class functor-type words. One important intervention may, again, relate to training listeners. Hustad (2006) suggested that one avenue to help listeners decipher content-related open class words more readily might be to provide instructions directing listeners to attend closely to the words that they have more difficulty understanding (open class content words). Another option may be to develop and validate linguistic bootstrapping strategies in which listeners use closed-class syntactic words to aid in deciphering open class content words. It may also be helpful for listeners to engage in explicit comprehension monitoring activities to help them get feedback regarding their interpretation of messages produced by speakers with dysarthria. Studies that explore instructional techniques and their effectiveness for training listeners to make use of any and all information available when presented with dysarthric speech should be considered.

Acknowledgments

The authors thank the speakers with dysarthria who participated in this project. Research was funded by grant R03 DC005536 from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health.

References

Berry, R. A., & Knight, R. E. (1975). Auditory versus audio-visual intelligibility measurements of alaryngeal speech: A preliminary report. *Perceptual and Motor Skills*, *40*, 915–918.

Cutler, A. (1993). Phonological cues to open- and closed-class words in the processing of spoken sentences. *Journal of Psycholinguistic Research*, *22*, 109–131.

Erber, N. E. (1975). Auditory-visual perception of speech. *Journal of Speech and Hearing Disorders*, *40*, 481–492.

Duffy, J. (2005). Motor Speech Disorders: Substrates, Differential Diagnosis, and Management (second edition). St. Louis, MI: Mosby.

Garcia, J. M., & Dagenais, P. A. (1998). Dysarthric sentence intelligibility: Contribution of iconic gestures and message predictiveness. *Journal of Speech, Language, and Hearing Research*, *41*, 1282–1293.

Garcia, J., & Cannito, M. (1996). Top-down influences on the intelligibility of a dysarthric speaker: Addition of natural gestures and situational context. In D. Robin, K. Yorkston, & D. Beukelman (Eds.), *Disorders of Motor Speech: Assessment, Treatment, and Clinical Characterization* (pp. 89–103). Baltimore, MD: Paul H. Brookes.

Grosjean, F., & Gee, J. P. (1987). Prosodic structure and spoken word recognition. *Cognition*, *25*, 135–155.

Howell, D. C. (2002). *Statistical Methods for Psychology* (fifth edition). Belmont, CA: Duxbury Press.

Howell, D. C. (2004). *Fundamental Statistics for the Behavioral Sciences* (fifth edition). Belmont, CA: Duxbury Press.

Hubbard, D. J., & Kushner, D. (1980). A comparison of speech intelligibility between esophageal and normal speakers via three modes of presentation. *Journal of Speech and Hearing Research*, *23*, 909–916.

Hunter, L., Pring, T., & Martin, S. (1991). The use of strategies to increase speech intelligibility in cerebral palsy: An experimental evaluation. *British Journal of Disorders of Communication*, *26*, 163–174.

Hustad, K. C. (2006). A closer look at transcription intelligibility for speakers with dysarthria: Evaluation of scoring paradigms and linguistic errors made by listeners. *American Journal of Speech Language Pathology*, *15*, 268–277.

Hustad, K. C. (in press). Contribution of two sources of linguistic knowledge to intelligibility of speakers with cerebral palsy. *Journal of Speech, Language, and Hearing Research.*

Hustad, K. C., & Beukelman, D. R. (2001). Effects of linguistic cues and stimulus cohesion on intelligibility of severely dysarthric speech. *Journal of Speech, Language, and Hearing Research*, *44*, 497–510.

Hustad, K. C., & Beukelman, D. R. (2002). Listener comprehension of severely dysarthric speech: Effects of linguistic cues and stimulus cohesion. *Journal of Speech, Language, and Hearing Research*, *45*, 545–558.

Hustad, K. C., & Cahill, M. A. (2003). Effects of presentation mode and repeated familiarization on intelligibility of dysarthric speech. *American Journal of Speech-Language Pathology*, *12*, 1–11.

Hustad, C. K., & Garcia, M. J. (2005). Aided and Unaided Speech Supplementation Strategies: Effect of Alphabet Cues and Iconic Hand Gestures on Dysarthric Speech. *Journal of Speech, Language, and Hearing Research*, *48*, 996–1012.

Hustad, K. C., & Weismer, G. (2007). A Continuum of Interventions for Individuals with Dysarthria: Compensatory and Rehabilitative Treatment Approaches. In G. Weismer (Ed.), *Motor Speech Disorders*. San Diego, CA: Plural Publishing.

Keintz, C., Bunton, K., & Hoit, J. (in press). Influence of visual information on the intelligibility of dysarthric speech. *American Journal of Speech Language Pathology*.

Kent, R. D., & Adams, S. G. (1989). The concept and measurement of coordination in speech disorders. In S. A. Wallace (Ed.), *Perspectives on the coordination of movement* (pp. 415–450). Amsterdam: Elsevier.

Kirk, R. (1995). *Experimental design: Procedures for the behavioral sciences* (third edition). Pacific Grove, CA: Brooks/Cole Publishing.

Klasner, E. R., & Yorkston, K. M. (2005). Speech intelligibility in ALS and HD dysarthria: The everyday listener's perspective. *Journal of Medical Speech Language Pathology*, *13*, 127–139.

Marascuilo, L., & Serlin, R. (1988). *Statistical Methods for the Social and Behavioral Sciences*. New York: W. H. Freeman and Company.

Monsen, R. B. (1983). The oral speech intelligibility of hearing-impaired talkers. *Journal of Speech and Hearing Disorders*, *43*, 286–296.

Neely, K. K. (1956). Effects of visual factors on the intelligibility of speech. *Journal of the Acoustical Society of America*, *28*, 1275–1277.

O'Neill, J. J. (1957). Recognition of intelligibility test materials in context and isolation. *Journal of Speech and Hearing Disorders*, *22*, 87–90.

Pichney, M. A., Durlach, N. I., & Braida, L. D. (1986). Speaking clearly for the hard of hearing II: Acoustic characteristics of clear and conversational speech. *Journal of Speech and Hearing Research*, *29*, 434–446.

Platt, L. J., Andrews, G., & Howie, P. (1980). Dysarthria of adult cerebral palsy: II. Phonemic analysis of articulation errors. *Journal of Speech and Hearing Research*, *23*, 41–55.

Sanders, D. A., & Goodrich, S. J. (1971). The relative contribution of visual and auditory components of speech to speech intelligibility as a function of three conditions of frequency distortion. *Journal of Speech and Hearing Research*, *14*, 154–159.

Sound Forge 4.5 (1998). Computer software. Madison, WI: Sonic Foundry.

Turner, G. S., & Tjaden, K. (2000). Acoustic differences between content and function words in amyotrophic lateral sclerosis. *Journal of Speech, Language, and Hearing Research*, *43*, 769–781.

Weismer, G., & Martin, R. (1992). Acoustic and perceptual approaches to the study of intelligibility. In R. Kent (Ed.), *Intelligibility in Speech Disorders* (pp. 67–118). Philadelphia, PA: John Benjamins Publishing Co.

Yorkston, K., Beukelman, D., & Tice, R. (1996). Sentence Intelligibility Test for Windows. Lincoln: Communication Disorders Software. Distributed by the Institute for Rehabilitation Science and Engineering, Lincoln, NE.