2012-06-04

The Effect of an Artificially Flattened Fundamental Frequency Contour on Intelligibility in Speakers with Dysarthria

Emily E. Redd
Brigham Young University - Provo

The Effect of an Artificially Flattened Fundamental Frequency Contour

on Intelligibility in Speakers with Dysarthria

Emily Elizabeth Redd

A thesis submitted to the faculty of
Brigham Young University
in fulfillment of the requirements for the degree of

Master of Science

Christopher Dromey, Chair
Shawn L. Nissen
Ron W. Channell

Department of Communication Disorders

Brigham Young University

June 2012

ABSTRACT

The Effect of an Artificially Flattened Fundamental Frequency Contour
on Intelligibility in Speakers with Dysarthria

Emily Elizabeth Redd
Department of Communication Disorders, BYU
Master of Science

Prosody plays an important role in speech communication. Many individuals with motor speech disorders have decreased prosodic control and thus lower overall intelligibility. Few studies have examined the effect of a flattened prosodic contour on the intelligibility of dysarthric speech, and little is known about the role that listener gender plays in understanding disordered speech.

The purpose of this study was to quantify the impact of artificial prosodic manipulation on the intelligibility of dysarthric speech as a function of the extent of fundamental frequency (F_0) contour flattening. A further goal was to examine the influence of listener gender on intelligibility. Speech recordings from two speakers (one with mild dysarthria and one with severe dysarthria) were synthetically altered by reducing F_0 variability by 50%, 75%, and 100%. Fifty listeners transcribed the sentences and rated the perceived difficulty of the task. Results of the study indicated that a flattened F_0 contour led to decreases in the intelligibility of both speakers with dysarthria, both in terms of transcription accuracy and ratings of listener confidence. All altered conditions resulted in poorer intelligibility than the unaltered utterances. For the mild speaker, scores and ratings decreased predictably in proportion to the extent of F_0 flattening, whereas for the severe speaker, there was not a steady decrease in intelligibility as the F_0 was progressively flattened. The utterances were more intelligible to female than male listeners.

ACKNOWLEDGEMENTS

There are so many people that I would like to thank for helping me along this journey. It has been an adventure! First, I express my deep appreciation to my thesis chair, Dr. Dromey. I could not have done this without his help. I would also like to thank my committee members, Dr. Nissen and Dr. Channell, for their additional insights.

Next, I thank all of the participants of this study who through their participation made this research possible.

My heartfelt thanks also go to my cohort of classmates. Thanks to each of you for being there for me throughout my graduate experience.

Finally, I thank my family and friends for all of their support during this important time in my life. Thanks to each of you for your love, patience, and words of encouragement. I express a special thanks to my parents for teaching me the value of education and always encouraging me to be my very best. I can never thank you both enough.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

DESCRIPTION OF STRUCTURE AND CONTENT

This thesis is presented in a hybrid format where current journal publication formatting is blended with traditional thesis requirements. The introductory pages are therefore a reflection of the most up to date university requirements while the thesis report reflects current length and style standards for research published in peer reviewed journals for communication disorders. Appendix A is composed of an annotated bibliography. Appendix B includes the informed consent forms for the speakers and listeners. Appendix C includes the speech recording stimuli.

Introduction

Speech is produced as a series of syllables, words, and sentences. It is a highly complex task that involves the precise and rapid coordination of cognitive-linguistic processing, motor programming, and neuromuscular execution. These elements combine with important suprasegmental aspects of speech, including prosody, to complete a speaker's message and convey emotion in order for intelligible, meaningful communication to occur (Duffy, 2005; Laures & Weismer, 1999; Patel & Campellone, 2009). Breakdowns in communication arise when one or more of these elements are absent or disturbed, often as the result of neurologic disease (Cutler, Dahan, & van Donselaar et al., 1997; Darley, Aronson, and Brown, 1969).

It has been well established that prosody plays an important role in speech communication (Bunton, Kent, Kent, & Duffy, 2001; Laures & Weismer, 1999; Yorkston & Beukelman, 1981). Prosody refers to "the variations in pitch, stress, and timing of speech" (Patel & Grigos, 2006, p. 1308) that help communicate a speaker's meaning and emotion in conversation (Plante & Beeson, 2004). The acoustic features of prosody include fundamental frequency (F_0), duration, and intensity, which correspond to a listener's perception of pitch, timing, and loudness (Patel & Campellone, 2009).

The prosodic features of speech serve two functions—to clarify linguistic meaning and to convey the speaker's emotion (Patel & Campellone, 2009). Linguistic prosody helps the listener understand the meaning of a speaker's message. Such prosodic cues can mark word and phrase boundaries, clarify lexical ambiguities through stress and emphasis, signal sentence types (i.e. statements versus questions), and emphasize contrasts. Affective functions of prosody serve to aid the listener in understanding the speaker's attitudes and emotions and to support linguistic prosodic cues (Dupois & Pichora-Fuller, 2010; Patel & Campellone, 2009). Both linguistic and affective prosody play an important role in understanding a speaker's overall message.

Research has also established that women tend to perceive emotion, including important prosodic cues, differently than men. In a study conducted by Schirmer, Zysset, Kotz, and Yvees von Cromon (2004), functional magnetic resonance imaging (fMRI) showed that semantic processing in women is more susceptible to influences from emotional prosody than semantic processing in men. Hofer et al. (2006) also used fMRI to investigate the role that gender plays in the perception of emotion. Their data suggested clear gender-related neural responses to emotional stimuli. In a study targeting affective facial expressions, Montagne, Kessels, Frigerio, Haan, and Perrett (2004) found that women outperformed men in labeling appropriate facial expressions. In a study that measured the identification of angry versus neutral intonation, Dromey, Silveira, and Sandor (2005) also found that women were more accurate than men in perceiving emotional prosody. The results of these studies suggest that women may tend to perceive prosodic cues better than men.

Although it is difficult to quantify the extent to which prosodic cues contribute to the listener's comprehension, researchers have found that such cues do indeed make a difference (Cutler et al., 1997). Stine and Wingfield (1987) suggested that prosodic cues help a listener's top-down processing, which in turn aids overall language understanding. Blasko and Hall (1998) showed that inconsistent prosody slowed listener comprehension and contributed to less accurate judgments of sentence meaning. Stine and Wingfield (1987) argued that better initial comprehension of a speaker's message might positively affect recall of that message over time. They found that redundancy and use of prosodic cues including "focal stress that highlights key words [are] especially beneficial to the older adult for cued recall" (p. 273). Additionally, immediate recall was improved in both young and elderly adults when prosodic cues were implemented.

For several decades, researchers have measured the acoustic features of prosody in healthy and dysarthric speakers (Darley et al., 1969; Patel, 2003; Patel & Campellone, 2009; Patel & Grigos, 2006).   Less in known, however, about the impact of disordered prosody on intelligibility in speakers with dysarthria and how this impact may differ among dysarthria subtypes. A better understanding of the impact of prosodic control in dysarthric speech may have significant clinical value.

Several studies have established that variability in F_0 is particularly important in speaker intelligibility and that F_0 variability in dysarthric speech is significantly reduced (Bunton et al., 2001; Patel & Campellone, 2009; Yorkston & Beukelman, 1981). Other studies have shown that highly intelligible speakers produce sentences with a relatively wide range of F_0 (Bunton et al., 2001; Laures & Weismer, 1999). In dysarthric speech the range of F_0 is often limited, and disordered prosodic control in some forms of dysarthria can result in monopitch and/or monoloud utterances (Darley et al., 1969). Consequently, the listener's ability to identify word and phrase boundaries, lexical meanings, and sentence types may be diminished. Affective meaning may also be lost. As a result, the reduced F_0 variation in dysarthric speech can limit intelligibility.

A number of studies have found that in spite of their physiologic limitations, many individuals with dysarthria have at least some preserved ability to mark prosodic contrasts. Patel and Campellone (2009) found that adult speakers with dysarthria rely more heavily on changes in duration than changes in fundamental frequency or intensity to signal contrastive stress within short sentences. Patel (2003) also found that children and adults could control the fundamental frequency and duration of vowels despite overall reduced intelligibility.

Laures and Weismer (1999) conducted a study that examined the effect of F_0 variation on the intelligibility of speakers with no history of neurologic speech disorders. Two healthy speakers produced sentences that were later re-synthesized using a computer software program that changed the F_0 contour without altering formant frequencies or speech timing. Listeners with normal hearing then rated the intelligibility of the unaltered utterances and those that had been artificially altered. The results showed significantly decreased intelligibility for the sentences with artificially flattened F_0 contours. The study did not include speakers with dysarthria.

Bunton et al. (2001) examined how a lack of sentence-level F_0 variation contributes to reduced intelligibility in speakers with dysarthria secondary to Parkinson's disease and unilateral upper motor neuron disease. Four speakers diagnosed with Parkinson's disease, four with left cerebrovascular accident, and two with right cerebrovascular accident produced sentence-length utterances that were later altered using a re-synthesis program that altered the F_0 contour. Listeners with normal hearing used a perceptual rating scale and performed a transcription task to measure intelligibility. Results of the study supported the finding that F_0 variations are important for speech intelligibility and suggested that the degree of importance may vary with dysarthria type.

Speech synthesis software is sometimes used to understand specific speech parameters that cannot be controlled in natural speech production (Bunton et al., 2001; Laures & Weismer, 1999). Praat is a speech analysis and synthesis software package that is commonly used in research. It allows sentence level fundamental frequency modifications without affecting formant frequencies or speech timing (Boersma & Weenink, 2011; Bunton et al., 2001; Laures & Weismer, 1999).

Although previous studies have concluded that reduced F_0 variation adversely affects intelligibility (Laures & Weismer, 1999), studies using this same procedure for speakers with dysarthria are limited. It would be of theoretical and clinical interest to know the extent to which F_0 variation contributes to intelligibility deficits in dysarthric speech and the degree to which prosody may be synthetically altered in dysarthric speech before significantly impacting intelligibility. It would also be of interest to understand the role that gender plays in the perception of prosodic cues affecting intelligibility. The present study was designed to extend the findings of Laures and Weismer (1999) and Bunton et al. (2001) in speakers with dysarthria. The purpose of the study was to quantify the impact of artificial F_0 manipulation on intelligibility in dysarthric speech as a function of the extent of F_0 contour flattening, and also to examine the effect of listener gender.

Methods

Participants

Speakers. Speech samples were provided by two men with dysarthria, one severe and one mild, secondary to cerebral palsy. The speaker with severe dysarthria (age 23) was receiving speech therapy services at the Brigham Young University Speech-Language Clinic at the time of the study, whereas the speaker with mild dysarthria (age 33) had received speech therapy services within the previous year. Speech therapy goals for both speakers focused on improving overall intelligibility. Both were native English speakers.

Listeners. Fifty young adults participated as listeners. There were 32 women (ages 18-32 years; $M = 20.5$, $SD = 3.5$) and 18 men (ages 22-31 years; $M = 23.5$, $SD = 0.7$). Each listener was required to pass a hearing screening at 20 dB HL at octave frequencies from 500 to 8000 Hz bilaterally. All of the listeners were native English speakers with no significant history of speech, language, or hearing problems as determined by self-report.

All study participants were recruited from the Brigham Young University community and surrounding areas and signed an IRB consent form (see Appendix A) indicating willingness to participate in the research study.

Instrumentation

Speech recordings. The speakers were seated in a sound booth while their speech was recorded with an AKG C-420 head-mount condenser microphone. A 4 centimeter mouth to microphone distance was maintained throughout the data collection. The speech signal was passed through a Samson Mixpad 4 preamplifier to a Kay Elemetrics CSL 4400 analog-to-digital recording system, sampling at 44.1 kHz with 16 bit quantization. In cases of peak clipping or other errors, the test items were re-recorded.

Listening task. The stimuli were presented to each listener over loudspeakers in a sound booth. Prior to the listening task, each speaker was permitted to adjust the volume of the loudspeakers to a comfortable listening level.

Procedure

Speaking task. The speakers were presented with a list of sentence stimuli and asked to read them using their habitual pitch, loudness, and rate. The stimuli consisted of 50, seven-word, low predictability sentences, which were developed to be grammatically correct, yet difficult for listeners to guess based on their content. The use of these sentences was intended to avoid artificial inflation of intelligibility scores (McHenry & Parle, 2006). The sentences used in the study, including written instructions to the speakers, can be found in Appendix B. Each recording session was completed in approximately 30 minutes.

Speech sample re-synthesis. Praat acoustic analysis software (version 5.2.46) was used to re-synthesize the speech samples (Boersma & Weenink, 2011). This program enabled sentence level F_0 modifications that did not affect formant frequencies or speech timing. First,

the median F_0 for each sentence was calculated. In the first condition, the F_0 contour was flattened by 50%, thus reducing the peaks and valleys in the contour to one half of their previous values. In the second condition, the F_0 contour was flattened by 75%. For the third condition, the F_0 contour was flattened completely by changing the entire F_0 contour to match the median F_0 of the sentence.

Listening task. Prior to listening, each participant was familiarized with the task and given oral instructions. Each listening session was completed in approximately 20-30 minutes.

The listeners were divided into ten groups, with five listeners assigned to each group. The stimuli were presented by a custom Matlab software application. Prior to the task, each listener was provided two practice stimuli to allow them to select a comfortable loudness level. Each listening group was presented a total of 40 sentences previously recorded by each of the speakers. Of the first 20 sentences produced by the speaker with severe dysarthria, each listening group was presented 5 sentences of unaltered speech and 5 sentences of each altered condition (i.e. 5 sentences each of a F_0 contour reduced by 50%, 75%, and 100%). The procedure was then repeated for the second 20 sentences produced by the speaker with mild dysarthria. All of the stimuli were carefully counterbalanced so that no two listening groups were presented the same sentences in either the unaltered or prosody-altered conditions.

To obtain intelligibility scores, each listener participated in a transcription and a rating task. Using a custom Matlab program, each listener heard a stimulus sentence twice and then transcribed what he or she heard. They then rated their level of confidence in understanding what was said using a mouse-controlled slider on a 100-point scale (0 = "understood nothing" to 100 = "understood completely").

Data Analysis

The main independent variable was the degree of prosodic flattening, which had four

levels (i.e. unaltered speech and reduction of the F_0 contour by 50%, 75%, and 100%). The

second independent variable was the speaker—one with severe and one with mild dysarthria.

Listener gender was a third independent variable. The dependent variables were the intelligibility

scores (transcription accuracy and listener confidence rating).

Intelligibility scores for the transcription task for each listener were calculated for each

condition as a score out of 35 (7 words for each of the 5 sentences). Punctuation, mild

misspellings (i.e. misspellings with no more than one error or misspellings that did not change

word meaning), and homophones did not affect intelligibility scores. Scores were then averaged

across each listening group. Scores for listener confidence ratings were calculated for each

condition as a score out of 500 (100 point maximum for each of the 5 sentences), and scores

were again averaged across each listening group.

Statistical Analysis

A one-way ANOVA was used to test for differences in the transcription and listener

confidence scores across the four prosody conditions (separately for the mildly and severely

dysarthric speakers), with Dunnett post-hoc tests to identify which conditions differed from each

other. A separate one-way ANOVA tested for differences between male and female listeners.

All testing was conducted with IBM SPSS Statistics (version 19).

<div align="center">

Results

</div>

The results are considered separately for speaker 1 (mild dysarthria) and speaker 2

(severe dysarthria).

F_0 Contour Conditions

The dependent measures changed significantly across the prosodic conditions.

Transcription intelligibility. Table 1 presents the means and standard deviations for the transcription task scores in each of the F_0 contour conditions for speaker 1. Figure 1 represents the same scores graphically, although the error bars in all figures represent the standard error of the mean, rather than the standard deviation. Transcription scores for speaker 1 showed an expected predictable decline corresponding to the progressive flattening of the F_0 contour. The ANOVA revealed a significant difference in the transcription scores across conditions ($F = 3.754$, $p = .032$). A one-tailed Dunnett post hoc test was used to compare the unaltered F_0 condition against the other conditions. Significant differences were found for the three-quarters reduced ($p = .027$), and the fully reduced conditions ($p = .009$).

Table 1

Speaker 1 (Mild Dysarthria) Intelligibility Scores—Transcription Accuracy

Condition	Mean (Score/35)	Standard Deviation
Original	34.27	.41
Half-reduced	33.96	.27
Three-quarters reduced	33.72	.28
Fully reduced	33.60	.37

Table 2 outlines the means and standard deviations for the transcription task scores for speaker 2, and Figure 2 represents the scores graphically. Transcription scores for speaker 2 decreased from the unaltered condition to the half-reduced condition but were maintained through the three-quarter-reduced and fully reduced conditions. The ANOVA showed a significant difference in the transcription task scores across conditions ($F = 3.594$, $p = .037$). Again using the unaltered F_0 condition as a baseline, a one-tailed Dunnett post hoc test showed significant differences for the half-reduced ($p = .043$), the three-quarters reduced ($p = .036$), and the fully reduced conditions ($p = .01$).

Figure 1. Transcription accuracy for each of the study conditions for speaker 1 (mild dysarthria). Error bars represent standard errors.

Table 2

Speaker 2 (Severe Dysarthria) Intelligibility Scores—Transcription Accuracy

Condition	Mean (Score/35)	Standard Deviation
Original	21.23	1.12
Half-reduced	18.83	1.47
Three-quarters-reduced	18.74	2.16
Fully-reduced	18.04	1.58

Listener confidence ratings. Table 3 presents the means and standard deviations for the listener confidence ratings in each of the prosody conditions for speaker 1. Figure 3 represents the same scores graphically. Listener confidence ratings for speaker 1 showed a general decrease that corresponded to the systematic flattening of the F_0 contour. The ANOVA revealed a significant difference in the listener confidence scores across conditions ($F = 3.351, p = .045$). A one-tailed Dunnett post hoc test compared the unaltered condition against the other conditions. There was no significant difference between the unaltered and the half-reduced conditions ($p = .287$); however, there were significant differences between the unaltered and the three-quarters reduced ($p = .018$) and the fully-reduced conditions ($p = .027$).

Table 3

Speaker 1 (Mild Dysarthria) Intelligibility Scores—Listener Confidence Ratings

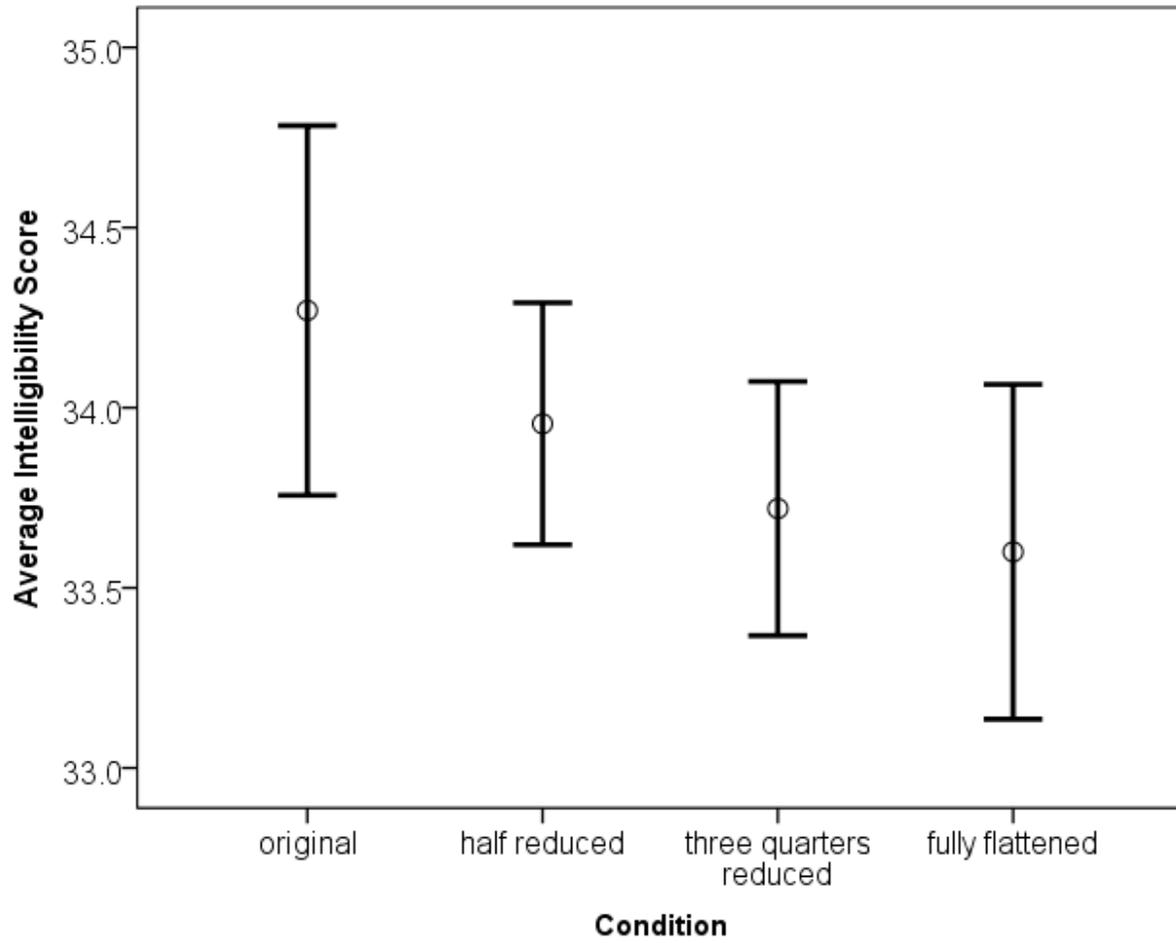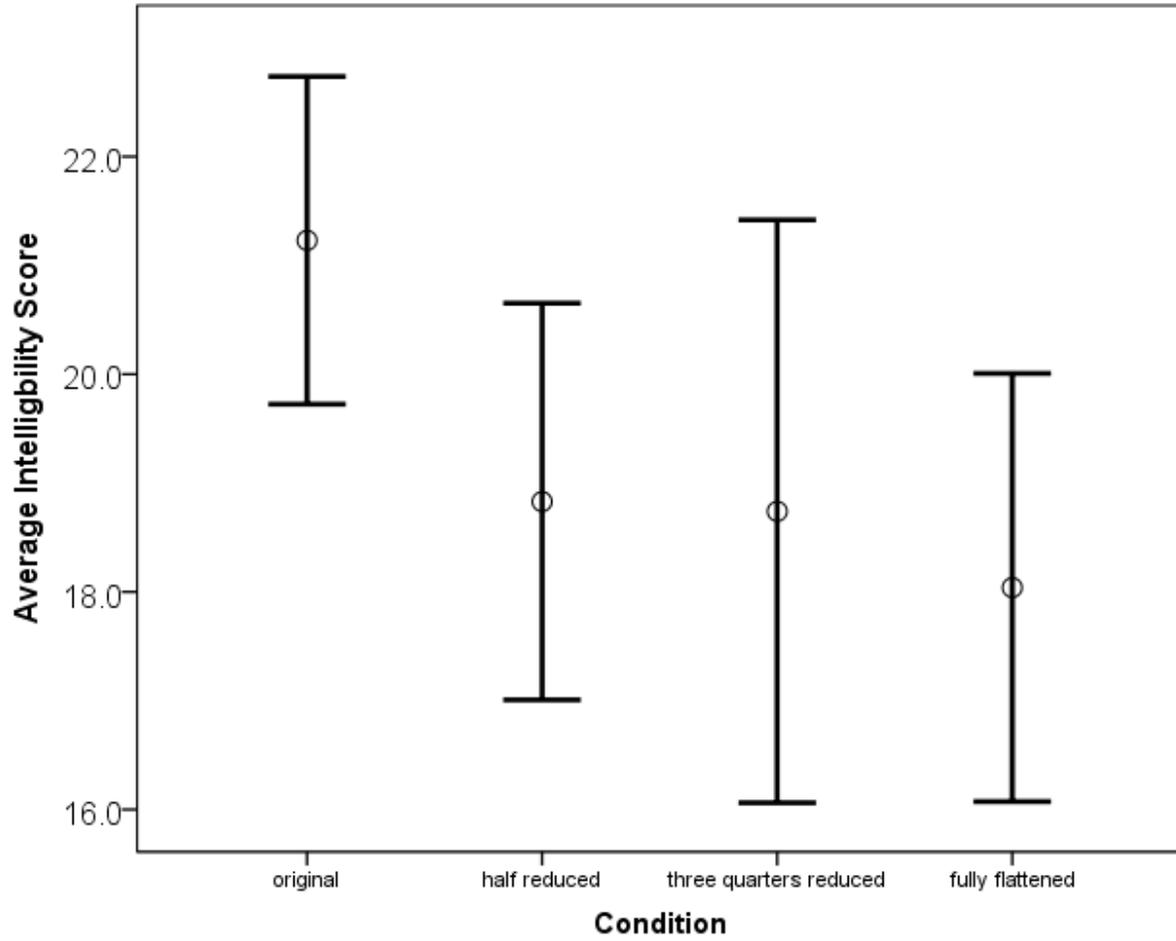| Condition	Mean (Score/500)	Standard Deviation
Original	470.78	12.54
Half-reduced	460.39	15.18
Three-quarters-reduced	445.21	12.52
Fully-reduced	455.87	17.18

Figure 2. Transcription accuracy for each of the study conditions for speaker 2 (severe dysarthria). Error bars represent standard errors.
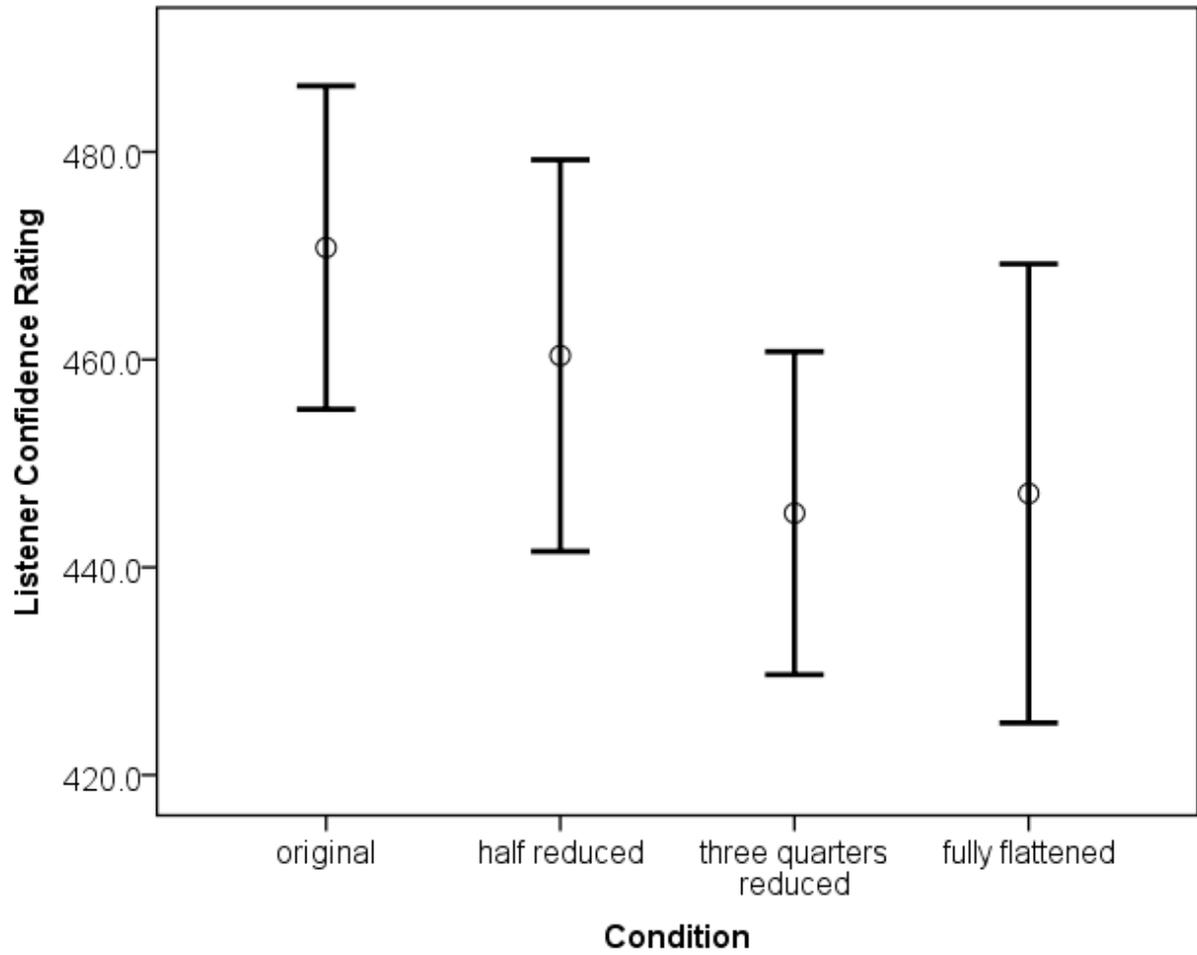
Figure 3. Listener confidence ratings for each of the study conditions for speaker 1 (mild dysarthria). Error bars represent standard errors.

Table 4 outlines the means and standard deviations for the transcription task scores for speaker 2, and Figure 4 represents the scores graphically. Listener confidence ratings decreased only for the fully-reduced condition. The ANOVA showed no significant differences in the listener confidence ratings across the conditions ($F = 1.650$, $p = .218$), and post hoc testing revealed no significant differences between the half-reduced ($p = .638$), the three-quarter reduced ($p = .780$), and the fully-reduced conditions ($p = .096$) compared with the unaltered sentences.

Table 4

Speaker 2 (Severe Dysarthria) Intelligibility Scores—Listener Confidence Ratings

Condition	Mean (Score/500)	Standard Deviation
Original	160.67	31.51
Half-reduced	155.46	25.94
Three-quarters-reduced	162.25	23.73
Fully-reduced	126.78	33.31

Listener Gender

Statistical analysis was conducted to determine whether or not there were gender effects on intelligibility ratings and listener confidence ratings. Results of the analysis revealed that there were gender differences both in terms of transcription accuracy and confidence ratings.

Transcription intelligibility. Table 5 presents the descriptive statistics for the effect that listener gender played during the transcription task. Figure 5 presents error bar plots of the transcription task scores by gender. For the mildly dysarthric speaker, a one-way ANOVA revealed that female listeners scored significantly better than their male counterparts ($F = 13.293$, $p = .001$). For the severely dysarthric speaker, transcription scores for both female and male listeners tended to decrease, corresponding to the systematic flattening of the F_0 contour.
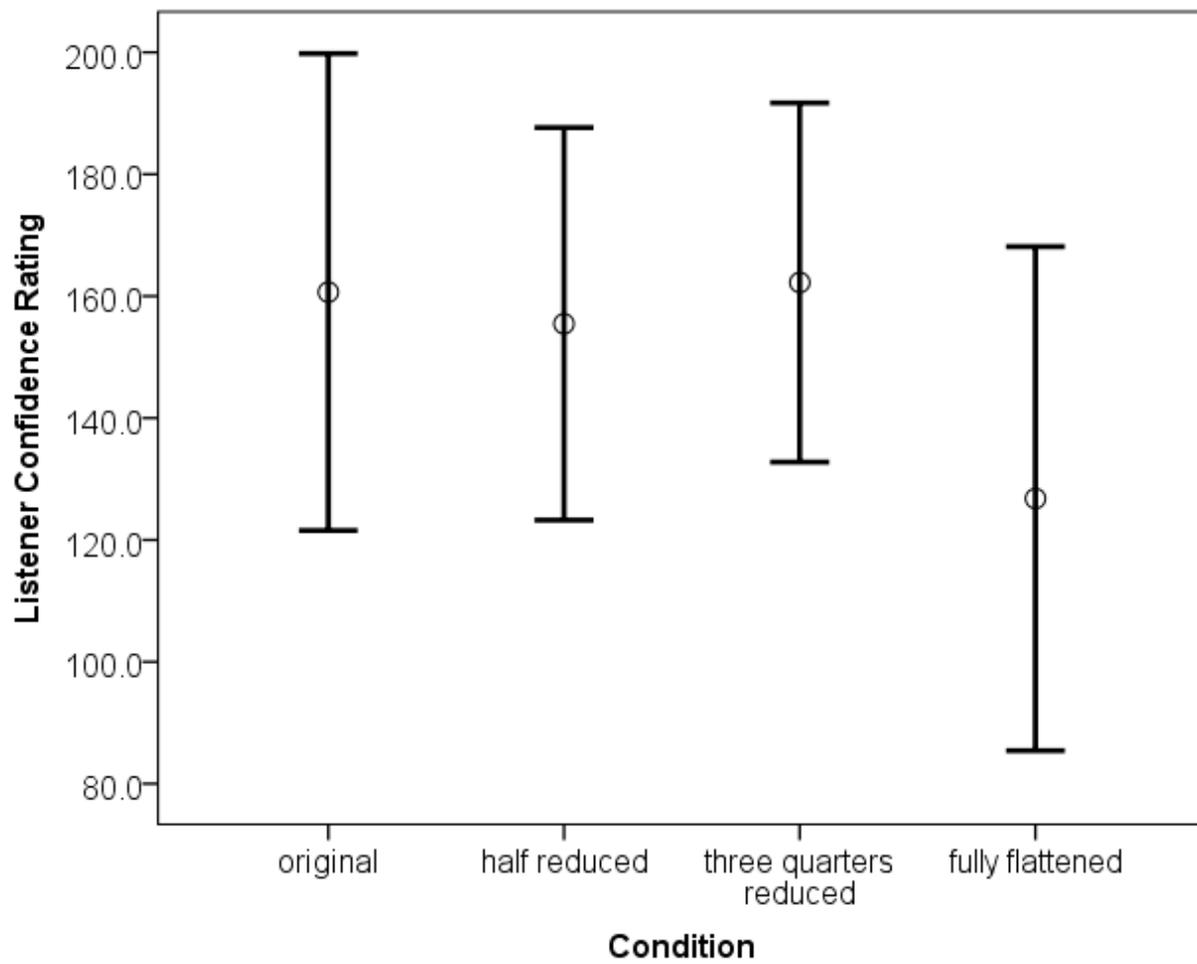
Figure 4. Listener confidence ratings for each of the study conditions for speaker 2 (severe dysarthria). Error bars represent standard errors.

Again, a one-way ANOVA showed that female listeners scored significantly higher than male listeners ($F = 10.456$, $p = .003$).

Table 5

Listener Gender Intelligibility Scores—Transcription Accuracy

Severity	Condition	Male		Female	
		Mean	SD	Mean	SD
Mild	Original	24.61	5.02	29.27	2.15
	Half-reduced	23.80	4.91	28.01	3.26
	Three-quarters reduced	24.72	5.05	28.45	2.20
	Fully reduced	24.44	4.88	28.50	2.08
Severity	Original	15.38	1.70	18.58	1.34
	Half-reduced	14.03	3.02	16.35	.827
	Three-quarters reduced	15.10	2.67	15.18	2.11
	Fully reduced	11.90	3.17	16.40	2.23

Listener confidence ratings. The means and standard deviations for the listener confidence ratings according to gender are listed in Table 6. This same information is presented graphically in Figure 6. For the mild speaker, a one-way ANOVA showed that female listeners scored statistically higher than male listeners ($F = 7.722$, $p = .008$). For the severe speaker, female and male listeners tended to score about the same. A one-way ANOVA showed no statistical significance between female and male confidence ratings ($F = .313$, $p = .579$).

Table 6

Listener Gender Intelligibility Scores—Listener Confidence Ratings

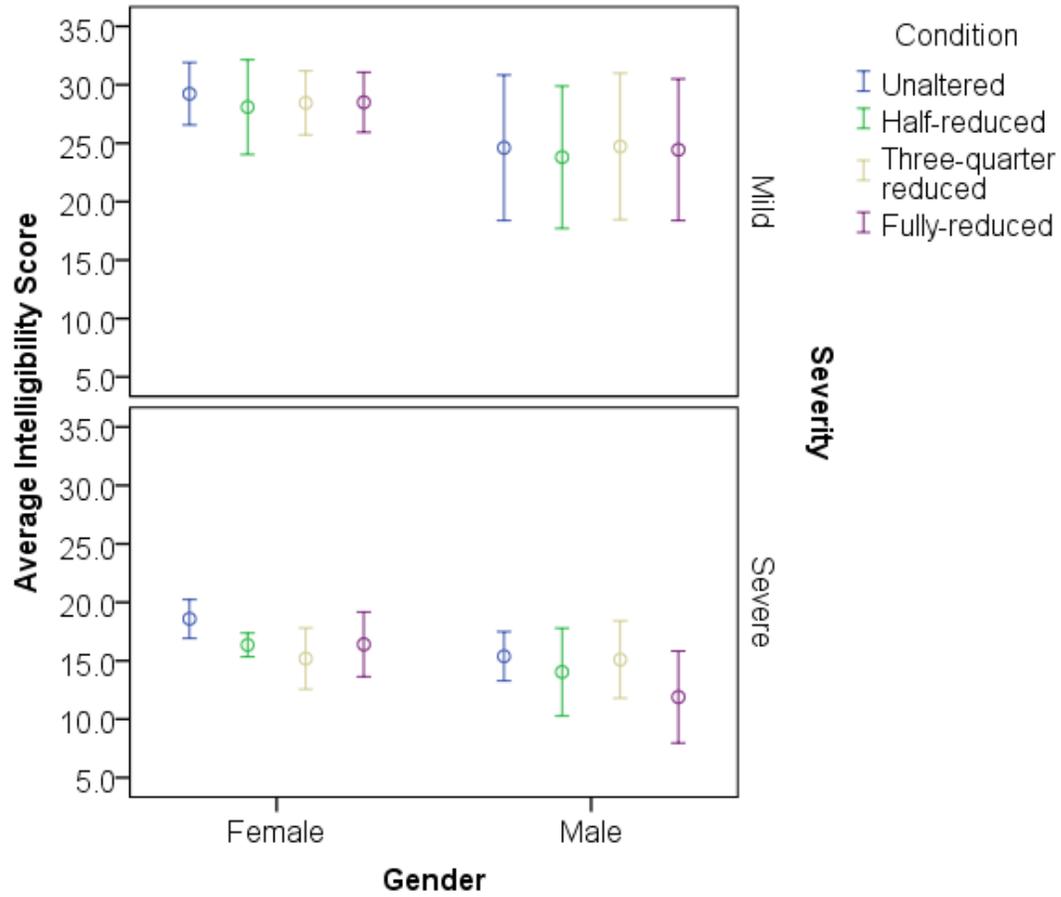| Severity	Condition	Male		Female	
		Mean	SD	Mean	SD
Mild	Original	341.54	73.57	393.90	46.44
	Half-reduced	324.82	65.64	373.80	63.36
	Three-quarters reduced	329.13	65.78	370.45	42.19
	Fully reduced	321.27	75.11	376.21	40.92
Severity	Original	120.16	8.30	138.05	31.51
	Half-reduced	123.92	55.18	129.21	25.06
	Three-quarters reduced	142.12	27.96	124.27	20.12
	Fully reduced	90.60	33.00	108.86	35.90

Figure 5. Transcription accuracy for each of the study conditions for speaker 1 (mild dysarthria) and speaker 2 (severe dysarthria) according to gender. Error bars represent standard errors.

Figure 6. Listener confidence ratings for each of the study conditions for speaker 1 (mild dysarthria) and speaker 2 (severe dysarthria) according to gender. Error bars represent standard errors.
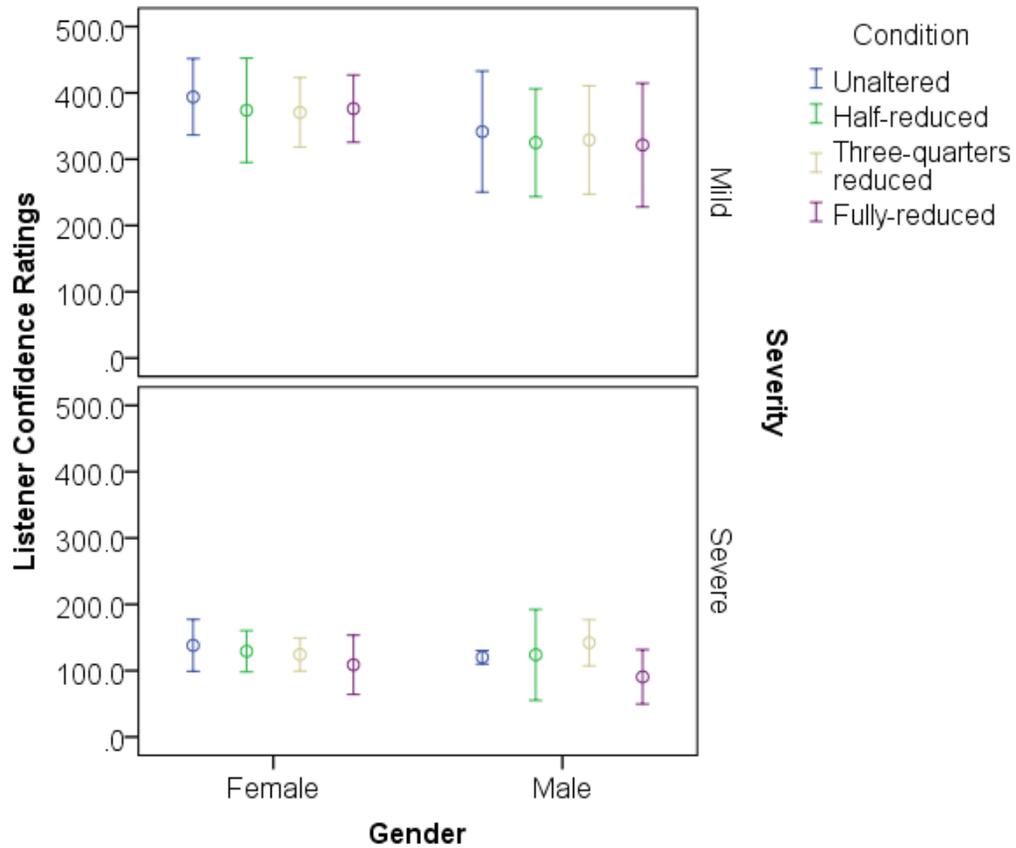
Listener experience. Because 16 speech-language pathology graduate students participated in the study as listeners, statistical analysis was conducted in order to measure potential listener experience bias. One-way ANOVAs revealed that there were no significant differences between speech-language pathology graduate students and naïve listeners, both in terms of intelligibility ratings ($F = .128$, $p = .721$) and listener confidence ratings ($F = 7.961$, $p = .165$).

Discussion

The purpose of the study was to measure the extent to which F_0 variation contributes to intelligibility deficits in dysarthric speech, or in other words, the degree to which prosody may be artificially reduced in dysarthric speech before significantly impacting intelligibility. The study was also designed to measure whether listener gender makes a difference to intelligibility scores. Recordings from two speakers (one with mild and one with severe dysarthria) were altered using software to reduce F_0 variability, and transcribed by 50 listeners who also completed a listener confidence rating task. The results indicated that a flattened F_0 contour decreased overall intelligibility in speakers with dysarthria and decreased listeners' confidence in their ability to understand.

For the mildly dysarthric speaker, transcription accuracy and listener confidence decreased as a function of the systematic flattening of the F_0 contour. For the severely dysarthric speaker, however, transcription scores and listener confidence were consistently poor. One of the principle questions guiding this experiment was the extent to which the F_0 contour may be flattened in order to have an impact on intelligibility. For both the mildly dysarthric and severely dysarthric speakers, any flattening of the F_0 contour adversely affected intelligibility; however, the effect appeared more quickly and dramatically for the severely dysarthric speaker. This may

indicate that the task was difficult for the listeners to begin with, and additional flattening of the F_0 contour did not make an important difference.

The results of the present study are consistent with those of previous studies (Bunton et al., 2001; Laures & Weismer, 1999), in that reducing F_0 variability had a significant, negative impact on sentence intelligibility. Despite their concordance, however, there are important differences between the experiments. Laures and Weismer (1999) studied the effect of sentence-level alterations to prosody on the intelligibility of speakers with no history of neurologic speech disorders. They also included an exaggerated prosody condition that was used for re-synthesis. Because prosody is known to contribute to overall intelligibility, the exaggerated prosody may have influenced transcription accuracy and/or listener confidence scores. Additionally, the extent and degree to which the artificial alterations were made also differed between studies. Nevertheless, despite the differences in speakers and re-synthesis, the effect of a flattened F_0 contour remained consistent. The present results, taken with those of Laures and Weismer (1999) and Bunton et al. (2001), support the finding that prosody plays an important role in conveying meaning, even in disordered speech.

A number of factors may relate to the contribution of prosody to intelligibility. First, Blasko and Hall (1999) determined that prosody is important in recognizing phrase and sentence boundaries. The variation of F_0 helps cue the listener to not only the beginnings and ends of phrases and sentences, but also the speaker's intended meaning. In dysarthric speech, where prosody may be impaired, the listener would have more difficulty in determining phrase and sentence boundaries, introducing ambiguity to the speaker's meaning. Synthetically altering the prosodic contour in dysarthric speech may introduce further ambiguity, making listener comprehension even more difficult.

Next, F_0 variation also helps direct the listener to important content words that are needed to understand sentence meaning. The F_0 contour at the beginning of a phrase or sentence can lead into and serve as a cue to high priority words that improve listener comprehension. Additionally, intentional changes to pitch, duration, and/or loudness can clarify or emphasize important content words also resulting in improved comprehension. Reductions in prosodic variation, such as those in dysarthric or synthetically altered speech, cause the listener to have more difficulty in recognizing high priority words, thereby reducing overall comprehension. When the context of the speaker's message is also unclear, as was the case in the present study with its low-predictability sentences, reduced F_0 variation would negatively affect listener comprehension even further.

With regard to gender effects, previous studies have shown no significant differences between male and female listeners in the intelligibility in speakers with dysarthria. Walshe, Miller, Leahy, and Murray (2007) and Whitehill and Ciocca (1997) found no statistically significant differences in overall intelligibility scores of dysarthric speech according to listener gender. In their study of the influence of listener characteristics on intelligibility in dysarthric speech, Pennington and Miller (2007) also found no significant differences between female and male listener intelligibility scores and suggested that either female or male listeners may be used in intelligibility research without the risk of inaccurate scoring.

In contrast to these previous findings, the present study found statistically significant differences between men and women in transcription accuracy and listener confidence ratings for the mildly dysarthric speaker and in transcription accuracy for the severely dysarthric speaker. There were higher scores for the female than the male listeners. The results suggest that gender

does play an important role in understanding dysarthric speech and that females tend to outperform than their male counterparts.

It is interesting to note that unlike listener gender, the results of the present study did not suggest that listener experience played an important role in understanding dysarthric speech. In fact, speech-language pathology graduate students tended to score slightly lower than their counterparts without formal exposure to speech disorders, both in terms of transcription accuracy and confidence ratings. However, these differences were not statistically significant.

Results from the present study add further evidence of the important role that prosody plays in listener comprehension. In dysarthric speech, where F_0 variability is already compromised, the effect of a flattened F_0 contour has an even greater adverse effect on overall speech intelligibility than in non-disordered speech. Additionally, listener gender appears to play an important role in understanding dysarthric speech, with females outperforming males.

The present study had several limitations that could be addressed in future research. First, although speakers with mild and severe dysarthria were included, only dysarthria secondary to cerebral palsy was considered. It is unclear whether the findings would be similar or potentially even more significant with other types of dysarthria. Next, the number of male and female listeners was not equal, including an unequal number of male and female speech-language pathology graduate student listeners. Finally, only modifications to the F_0 contour were made. The contributions of intensity and duration to prosody in dysarthric speech were not addressed.

Future experiments could include the analysis of recordings of various dysarthria subtypes and a more systematic sampling of listeners, allowing for a better balance between male and female listeners and a more representative sample of the general population. Finally, future

research is needed in order to address the contributions of intensity and durational aspects of

prosody to intelligibility in both normal and disordered speech.

References

Blasko, D. G., & Hall, M. D. (1998). Influence of prosodic boundaries on comprehension of

spoken English sentences. *Perceptual and Motor Skills, 87*, 3-18. doi:

10.2466/pms.1998.87.1.3

Boersma, P., & Wernink, D. (2011). Praat (Version 5.2.46) [Computer software].

Retrieved from http://www.fon.hum.uva.nl/praat/

Boutsen, F. (2003). Prosody: The music of language and speech. *The ASHA Leader*.

Retrieved from http://develop.asha.org/Publications/leader/2003/030304/030304f.htm

Bunton, K., Kent, R., Kent, J., & Duffy, J. (2001). The effects of flattening fundamental

frequency contours on sentence intelligibility in speakers with dysarthria. *Clinical

Linguistics & Phonetics, 15*(3), 181-193. doi: 10.1080/02699200010003378

Cutler, A., Dahan, D., & van Donselaar, W. (1997). Prosody in the comprehension of spoken

language: A literature review. *Language and Speech, 40*(2), 141-

201. doi: 10.1177/002383099704000203

Darley, F. L., Aronson, A. E., & Brown, J. R. (1969). Differential diagnostic patterns of

dysarthria. *Journal of Speech and Hearing Research, 12*, 246-269.

Duffy, J. R. (1995). *Motor speech disorders: Substrates, differential diagnosis, and

management.* (2nd ed.) St. Louis, MO: Mosby.

Dupuis, K., & Pichora, M. K. (2010). Use of affective prosody by young and older adults.

Psychology and Aging, 25(1), 16-29. doi: 10.1037/a0018777

Hofer, A., Siedentopf, C., Ischebeck, A., Rettenbacher, M., Verius, M., Felber, S., &

Fleischhacker, W. (2006). Gender differences in regional cerebral activity during the

perception of emotion: A functional MRI study. *Neuroimage, 32*, 854-862.

doi: 10.1016/j.neuroimage.2006.03.053

Hustad, K., Jones, T., & Dailey, S. (2003). Implementing speech supplementation strategies: Effects on intelligibility and speech rate of individuals with chronic severe dysarthria. *Journal of Speech, Language, and Hearing Research, 46*, 462-474. doi: 1092-4388/03/4602-0462

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*(3), 545-558. doi: 10.1044/1092-4388(2002/043)

Kim, Y., Kent, R., & Weismer, G. (2011). An acoustic study of the relationships among neurologic disease, dysarthria type, and severity of dysarthria. *Journal of Speech, Language, and Hearing Research, 54*(2), 417-429. doi: 10.1044/1092-4388(2010/10-0020)

Laures, J., & Weismer, G. (1999). The effects of a flattened fundamental frequency on intelligibility at the sentence level. *Journal of Speech, Language, and Hearing Research, 42*(5), 1148-1156.

Liss, J. M., Spitzer, S., Caviness, J. N., & Adler, C. (2002). The effects of familiarization on intelligibility and lexical segmentation in hypokinetic and ataxic dysarthria. *Journal of the Acoustical Society of America, 112*(6), 3022-3030. doi: 10.1121/1.1515793

Liss, J. M., Spitzer, S., Caviness, J. N., Adler, C., & Edwards, B. (1998). Syllabic strength and lexical boundary decisions in the perception of hypokinetic dysarthric speech. *Journal of the Acoustical Society of America, 104*(4), 2457-2466. doi: 10.1121/1.423753

McHenry, M. A., & Parle, A. M. (2006). Construction of a set of unpredictability sentences for intelligibility testing. *Journal of Medical Speech-Language Pathology, 14*(4), 269-271.

Montagne, B., Kessels, R., Frigerio, E., Haan, E., & Perrett, D. (2004). Sex differences in the

 perception of affective facial expressions: Do men really lack emotional sensitivity?

 Cognitive Processing, 6, 136-141. doi: 10.1007/s10339-005-0050-6

Norris, D., McQueen, J., Cutler, A., & Butterfield, S. (1997). The possible-word constraint in the

 segmentation of continuous speech. *Cognitive Psychology, 34*, 191-243. doi:

 10.1006/coqp.1997.0671

Patel, R. (2004). The acoustics of contrastive prosody in adults with cerebral palsy. *Journal of*

 Medical Speech-Language Pathology, 12(4), 189-193.

Patel, R. (2003). Acoustic characteristics of the question-statement contrast in severe dysarthria

 due to cerebral palsy. *Journal of Speech, Language, and Hearing Research, 46*, 1401-

 1415. doi:10.1044/1092-4388

Patel, R. (2002). Prosodic control in severe dysarthria: Preserved ability to mark the question-

 statement contrast. *Journal of Speech, Language, and Hearing Research, 45*, 858-870.

 doi:10.1044/1092-4388(2002/069)

Patel, R., & Campellone, P. (2009). Acoustic and perceptual cues to contrastive stress in

 dysarthria. *Journal of Speech, Language, and Hearing Research, 52*, 206-222. doi: 1092-

 4388/09/5201-0206

Patel, R., & Grigos, M. (2006). Acoustic characterization of the question-statement contrast in 4,

 7 and 11 year-old children. *Speech Communication, 48*, 1308-1318. doi:

 10.1016/j.specom.2006.06.007

Pennington, L., & Miller, N. (2007). Influence of listening conditions and listener characteristics

 on intelligibility of dysarthric speech. *Clinical Linguistics and Phonetics, 21*(5), 393-403.

 doi: 10.1080/02699200701276675

Schirmer, A., Zysset, S., Kotz, S., & Yvees von Cromon, D. (2003) Gender differences in the

    activation of inferior frontal cortex during emotional speech perception. *Neuroimage, 21*,

    1114-1123. doi: 10.1016/j.neuroimage.2003.10.048

Shriberg, E., Stolcke, A., Hakkani-Tur, D., & Tur, G. (2000). Prosody-based automatic

    segmentation of speech into sentences and topics. *Speech Communication, 32*, 127-154.

    doi: 10.1016/S0167-6393(00)00028-5

Stine, E., & Wingfield, A. (1987). Process and strategy in memory for speech among

    younger and older adults. *Psychology and Aging, 2*(3), 272-279. doi: 10.1037/0882-

    7974.2.3.272

Tjaden, K., & Wilding, G. (2004). Rate and loudness manipulations in dysarthria: Acoustic and

    perceptual findings. *Journal of Speech, Language, and Hearing Research, 47*, 766-783.

    doi: 1092-4388/04/4704-0766

Turner, G., & Weismer, G. (1993). Characteristics of speaking rate in the dysarthria associated

    with amyotrophic lateral sclerosis. *Journal of Speech & Hearing Research, 36*(6), 1134-

    1144.

Walsche, M., Miller, N., Leahy, M., & Murray, A. (2008). Intelligibility of dysarthric speech:

    Perceptions of speakers and listeners. *International Journal of Language and

    Communication Disorders, 43*(6), 6333-648. doi: 10.1080/13682820801887117

Watson, P., & Hughes, D. (2006). The relationship of vocal loudness manipulation to prosodic

    F0 and durational variables in healthy adults. *Journal of Speech, Language, and Hearing

    Research, 49*, 636-644. doi: 1092-4388/06/4903-0636

Whitehill, T., & Ciocca, V. (2000). Perceptual-phonetic predictors of single-word intelligibility:

A study of Cantonese dysarthria. *Journal of Speech, Language, and Hearing Research, 43*, 1451-1465. doi: 1092-4388/00/4306-1451

Wilson, D., & Wharton, T. (2005). Relevance and prosody. *Journal of Pragmatics, 38*(10), 1559-1579. doi: 10.1016/j.prgma.2005.04.012

Yorkston, K. M., & Beukelman, D. R. (1981). Communication efficiency of dysarthric speakers as measured by sentence intelligibility and speaking rate. *Journal of Speech and Hearing Disorders, 46,* 296-301.

Yunusova, Y., Weismer, G., Kent, R., & Rusche, N. (2005). Breath-group intelligibility in dysarthria: Characteristics and underlying correlates. *Journal of Speech, Language, and Hearing Research, 48*, 1294-1310. doi: 1092-4388/05/4806-1294

Appendix A—Annotated Bibliography

Blasko, D. G., & Hall, M. D. (1998). Influence of prosodic boundaries on comprehension of spoken English sentences. *Perceptual and Motor Skills, 87*, 3-18. doi: 10.2466/pms.1998.87.1.3

    The authors of this article investigated the role of prosody in the comprehension of sentences. Three experiments were conducted. In the first experiment, four individuals with normal speech read a set of sentence stimuli that were used in the two later experiments. The authors examined whether prosodic cues were produced consistently throughout the sentences. In the second experiment, 16 listeners were asked to identify phrase boundaries of the sentences based on the prosodic information given. In the third experiment, 40 listeners rated their understanding of sentences in which prosody was inconsistent with sentence meaning. Results of the experiments showed that inconsistent prosody slowed listener comprehension, indicating that prosodic cues contribute to successful auditory comprehension.

Bunton, K., Kent, R., Kent, J., & Duffy, J. (2001). The effects of flattening fundamental frequency contours on sentence intelligibility in speakers with dysarthria. *Clinical Linguistics & Phonetics, 15*(3), 181-193. doi: 10.1080/02699200010003378

    This study explored the relationship between fundamental frequency variability and speech intelligibility in speakers with dysarthria. Two speakers with dysarthria, one with hypokinetic dysarthria and one with unilateral upper motor neuron dysarthria, provided speech recordings that were altered and analyzed. A re-synthesis technique was used to flatten each speaker's prosody by 25%, 50%, and 100%. Speech intelligibility was measured using a word transcription task and an interval-scaling task. The results showed that speech intelligibility is strongly influenced by fundamental frequency, even when the range is severely restricted. The study also showed that the contribution of fundamental frequency to intelligibility may vary with different types of dysarthria.

Cutler, A., Dahan, D., & van Donselaar, W. (1997). Prosody in the comprehension of spoken language: A literature review. *Language and Speech, 40*(2), 141-201. doi: 10.1177/002383099704000203

    The authors of this article reviewed the literature related to the understanding of prosody in the comprehension of spoken language. They observed that research on the use of prosody generally fell into three main areas: the recognition of spoken words, the computation of syntactic structure, and the processing of discourse structure. Progress has been made in each of the three areas, particularly in understanding prosody's role in overall processing.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1969). Differential diagnostic patterns of dysarthria. *Journal of Speech Hearing Research, 12*, 246-269.

The authors examined the distinguishing characteristics of various forms of dysarthria. Thirty patients in each of seven discrete neurologic groups (i.e. bulbar palsy, pseudobulbar palsy, amyotrophic lateral sclerosis, cerebellar lesions, parkinsonism, dystonia, and choreoathetosis) provided 30-second speech samples for analysis. Three judges independently rated each sample using 38 criteria of speech and voice using a 7-point severity scale. Five dysarthrias were identified and defined: flaccid dysarthria, spastic dysarthria, ataxic dysarthria, hypokinetic dysarthria, and hyperkinetic dysarthria.

Dupuis, K., & Pichora, M. K. (2010). Use of affective prosody by young and older adults. *Psychology and Aging, 25*(1), 16-29. doi: 10.1037/a0018777

The purpose of this research was to examine the differences in understanding of linguistic and affective prosody between young and older adults. Three experiments were conducted. Twelve young, healthy and twelve older, healthy participants listened to sentences in which emotional cues conveyed by semantic content and affective prosody were congruent and incongruent and then asked to report the speaker's emotion. The listeners were then asked to repeat the presented sentences. Both age groups were able to effectively produce affective prosody. Results of the experiments indicated that young adults were attentive to affective prosodic cues whereas older adults performed less consistently when given the affective prosodic cues. The results also suggested that repetition of sentences by older adults may be used as a compensatory strategy to minimize a decrease in comprehension of affective prosody.

Hofer, A., Siedentopf, C., Ischebeck, A., Rettenbacher, M., Verius, M., Felber, S., & Fleischhacker, W. (2006). Gender differences in regional cerebral activity during the perception of emotion: A functional MRI study. *Neuroimage, 32*, 854-862. doi: 10.1016/j.neuroimage.2006.03.053

This study investigated the neural differences between men and women during the perception of positive and negative emotional stimuli. Using functional magnetic resonance imaging (fMRI), neural activations were measured in thirty-eight participants. Neural activations were observed in the right posterior cingulate, the left putamen, and the left cerebellum during presentation of positive emotional stimuli and in bilateral superior temporal gyri and cerebellar vermis during presentation of negative emotional stimuli. Results of the study suggested significant gender differences in neural activation areas.

Hustad, K., Jones, T., & Dailey, S. (2003). Implementing speech supplementation strategies: Effects on intelligibility and speech rate of individuals with chronic severe dysarthria. *Journal of Speech, Language, and Hearing Research, 46*, 462-474. doi: 1092-4388/03/4602-0462

The authors of this study compared speech intelligibility and speech rate differences following implementation of three supplementation strategies (topic, alphabet, and combined topic and alphabet supplementation) and a habitual speech control condition. Five speakers with severe dysarthria and 120 listeners participated in the study. Each speaker recorded three speech samples implementing each of three supplementation

strategies and non-cued speech. Each listener transcribed what he or she heard in each sample. Results of the study revealed that combined cues and alphabet cues yielded significantly higher intelligibility scores and slower speech rates than topic cues and non-cued speech.

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*(3), 545-558. doi: 10.1044/1092-4388(2002/043)

This study examined the effects of linguistic variables on listener processing of dysarthric speech and the relationship between intelligibility and comprehension. Four women with severe dysarthria secondary to cerebral palsy participated in the study. Participants recorded eight speech samples under four cue conditions (no cues, topic cues, alphabet cues, and combined cues), and listeners answered factual comprehension questions for the recorded sentences for each of the four cue conditions. Results of the study showed that combined cues resulted in higher comprehension scores and that alphabet cues resulted in higher comprehension than topic cues. Positive relationships between intelligibility and comprehension data were found only for topic cues in the unrelated-sentences condition and for alphabet cues in the related-sentences condition.

Kim, Y., Kent, R., & Weismer, G. (2011). An acoustic study of the relationships among neurologic disease, dysarthria type, and severity of dysarthria. *Journal of Speech, Language, and Hearing Research, 54*(2), 417-429. doi: 10.1044/1092-4388(2010/10-0020)

The authors of this study examined the acoustic predictors of speech intelligibility among speakers with various types of dysarthria secondary to neurologic disease. One hundred seven speakers with dysarthria secondary to Parkinson's disease, stroke, traumatic brain injury, and multiple system atrophy participated in the study. Each participant provided single word and sentence recordings. The recordings were analyzed acoustically and perceptually. Results of the study showed that acoustic predictors of speech intelligibility varied according to disease and that the accuracy of dysarthria classification is complicated by the degree of severity.

Laures, J., & Weismer, G. (1999). The effects of a flattened fundamental frequency on intelligibility at the sentence level. *Journal of Speech, Language, and Hearing Research, 42*(5), 1148-1156.

The purpose of this study was to examine the effect of a flattened fundamental frequency contour on speech intelligibility. Two male speakers recorded low-probability sentences. The sentences were then resynthesized with a flattened fundamental frequency contour. Intelligibility scores were derived from ten listeners through a transcription task and an interval rating scale. Results of the study showed that both measures were significantly lower when the fundamental frequency contour was flattened.

Liss, J. M., Spitzer, S., Caviness, J. N., & Adler, C. (2002). The effects of familiarization on

intelligibility and lexical segmentation in hypokinetic and ataxic dysarthria. *Journal of the Acoustical Society of America, 112*(6), 3022-3030. doi: 10.1121/1.1515793

The authors of this study evaluated the intelligibility of hypokinetic and ataxic dysarthric speech after a brief listener familiarization task. It was hypothesized that familiarized listeners would be able to extract relevant segmental and suprasegmental information better than non-familiarized listeners. Listeners transcribed phrases of hypokinetic and ataxic dysarthric speech after being familiarized with other phrases produced by the same dysarthric speakers. Results of the study showed that the familiarized listener group performed better than the non-familiarized listener group, and the effects were greater when the dysarthria type of the familiarization produced was the same as the dysarthria type of the transcription task. No differences in lexical boundary error patterns were identified between the two listener groups. The authors of the study suggested that reduced intelligibility in dysarthric speech is the result of the perceptual challenges caused by the reduced segmental and suprasegmental aspects of the signal, but that familiarization may aid in increasing intelligibility.

Liss, J. M., Spitzer, S., Caviness, J. N., Adler, C., & Edwards, B. (1998). Syllabic strength and lexical boundary decisions in the perception of hypokinetic dysarthric speech. *Journal of the Acoustical Society of America, 104*(4), 2457-2466. doi: 10.1121/1.423753

The purpose of this study was to evaluate the possible source of reduced intelligibility in speakers with hypokinetic dysarthria. The authors examined the mismatch between listeners' perceptions and the acoustic information of hypokinetic dysarthric speech. Seventy listeners heard 60 phrases of hypokinetic dysarthric speech, ranging from three to five words. The phrases alternated strong and weak syllables. Listener responses were recorded. Results of the analysis showed that listeners attend to strong syllables to segment connected speech and that there is a mismatch between listeners' perceptions and the acoustics of hypokinetic dysarthric speech, leading to overall reduced intelligibility.

Montagne, B., Kessels, R., Frigerio, E., Haan, E., & Perrett, D. (2004). Sex differences in the perception of affective facial expressions: Do men really lack emotional sensitivity? *Cognitive Processing, 6*, 136-141. doi: 10.1007/s10339-005-0050-6

This study examined the perception of affective facial expressions in men and women. Sixty-eight participants (40 female and 28 male) were presented neutral facial expressions that gradually morphed into emotional facial expressions and asked to label the emotional expression. Both labeling accuracy and sensitivity were measured. Results of the study showed that women outperformed men in both accuracy and sensitivity. The researchers concluded that women are better processors for affective facial expressions than men.

Norris, D., McQueen, J., Cutler, A., & Butterfield, S. (1997). The possible-word constraint in the segmentation of continuous speech. *Cognitive Psychology, 34*, 191-243. doi: 10.1006/coqp.1997.0671

In this study, the authors examined the role that constraints play in word recognition in continuous speech. In one experiment, 42 listeners were presented 96 bi-syllabic words with a strong-weak stress pattern. Each word was embedded into nonsense strings by the addition of a phonetic context. The listeners were asked to press a button every time they heard a nonsense word beginning or ending with a real word and then say the real word aloud. In a second experiment, the same procedure was followed with 43 listeners but with the target words cross-spliced between possible and impossible context conditions. The results of both experiments showed that listeners consistently found it easier to identify target words that are embedded in possible than in impossible contexts and that listeners tended to entertain segmentations which led to possible more than impossible words.

Patel, R. (2004). The acoustics of contrastive prosody in adults with cerebral palsy. *Journal of Medical Speech-Language Pathology, 12*(4), 189-193.

   The purpose of this study was to examine the use of contrastive stress within a phrase in individual speakers with cerebral palsy. Three speakers with severe dysarthria due to cerebral palsy and three healthy controls produced three, four-word phrases with contrastive stress placed on one of the four words. The phrases were then analyzed acoustically. All of the speakers were able to place contrastive stress at all four phrase locations and used fundamental frequency, intensity, and duration to mark the stress. The speakers with dysarthria were able to achieve fundamental frequency values in the same range as the control speakers and increased intensity to a greater extent than the control speakers.

Patel, R. (2003). Acoustic characteristics of the question-statement contrast in severe dysarthria due to cerebral palsy. *Journal of Speech, Language, and Hearing Research, 46*, 1401-1415. doi:10.1044/1092-4388

   This study examined how speakers with severe dysarthria due to cerebral palsy signal the question-statement contrast for short phrases. Eight speakers with dysarthria and eight healthy controls recorded a set of ten short phrases as both questions and statements. The recordings were analyzed acoustically using peak fundamental frequency, average fundamental frequency, slope of fundamental frequency, peak intensity, average intensity, slope of intensity, and duration measures for each syllable within each phrase. Results of the analysis revealed that both the speakers with dysarthria and the healthy controls used fundamental frequency, duration, and to a lesser degree, intensity cues to signal the contrast. It was also observed that the speakers with dysarthria produced longer and louder final syllables for questions compared to the healthy controls.

Patel, R. (2002). Prosodic control in severe dysarthria: Preserved ability to mark the question-statement contrast. *Journal of Speech, Language, and Hearing Research, 45*, 858-870. doi:10.1044/1092-4388(2002/069)

This study looked at whether speakers with dysarthria due to cerebral palsy used prosodic parameters of pitch contour and syllable duration for phrase-level productions. Eight speakers recorded three-syllable phrases as questions and statements. Forty-eight listeners were then asked to identify the recordings as either questions or statements. The study also examined how dysarthric speakers marked the question-statement contrast using the same recordings. Acoustic analysis showed that removing the pitch contour cues dramatically reduced listener accuracy in identifying questions and statements.

Patel, R., & Campellone, P. (2009). Acoustic and perceptual cues to contrastive stress in dysarthria. *Journal of Speech, Language, and Hearing Research, 52*, 206-222. doi: 1092-4388/09/5201-0206

In this study, the authors examined the acoustic and perceptual cues to contrastive stress in speakers with dysarthria versus healthy controls. Twelve speakers with dysarthria and twelve age- and gender-matched controls recorded a list of single words and short sentences. Changes in fundamental frequency, intensity, and duration were made and analyzed acoustically. Forty-eight healthy listeners were asked to identify the intended stress locations in both dysarthric and normal speech. Results of the study indicated that speakers with dysarthria relied more heavily on duration than on fundamental frequency or intensity to signal contrastive stress. Additionally, healthy listeners were highly consistent in identifying intended stress location.

Patel, R., & Grigos, M. (2006). Acoustic characterization of the question-statement contrast in 4, 7 and 11 year-old children. *Speech Communication, 48*, 1308-1318. doi: 10.1016/j.specom.2006.06.007

The authors of this study analyzed the question-statement contrast in young children at varying stages of development. Questions and declarative statements of twelve children from three age groups, ages four, seven, and eleven, were recorded and acoustically analyzed. The results of the analysis showed that 4-year-olds were unable to signal questions using rising fundamental frequency contour and used increased final syllable duration to mark questions. The 7-year-olds used fundamental frequency, intensity, and syllable duration to contrast questions from statements. The 11-year-olds relied primarily on changes in fundamental frequency to distinguish questions from statements. The distinctions among the three age groups demonstrate that children use different combinations of fundamental frequency, intensity, and syllable duration to mark question-statement contrast across development.

Pennington, L., & Miller, N. (2007). Influence of listening conditions and listener characteristics on intelligibility of dysarthric speech. *Clinical Linguistics and Phonetics, 21*(5), 393-403. doi: 10.1080/02699200701276675

The purposes of this study were to compare intelligibility of dysarthric speech under standard and non-standard listening conditions and to examine the role of listener age, gender, and familiarity with speaker accent on intelligibility. Seven speakers with cerebral palsy and 27 speakers with Parkinson's disease recorded single words. One

hundred twenty listeners were presented the recordings in standard and non-standard conditions and then asked to record what they heard. No differences were observed in intelligibility scores across the standard and non-standard listening conditions or across age, gender, or familiarity with speaker accent on intelligibility.

Schirmer, A., Zysset, S., Kotz, S., & Yvees von Cromon, D. (2003) Gender differences in the activation of inferior frontal cortex during emotional speech perception. *Neuroimage, 21*, 1114-1123. doi: 10.1016/j.neuroimage.2003.10.048

In this study, researchers used functional magnetic resonance imaging (fMRI) to examine the brain regions that process emotion when presented with words spoken with different types of prosody. Twenty-four participants (12 male and 12 female) were presented words with positive and negative prosody while their brains were scanned for neural activation areas. Results of the experiment showed that the left inferior frontal gyrus was more strongly activated in women than in men, suggesting that women are more sensitive to influences from emotional prosody than are men.

Stine, E., & Wingfield, A. (1987). Process and strategy in memory for speech among younger and older adults. *Psychology and Aging, 2*(3), 272-279. doi: 10.1037/0882-7974.2.3.272

The purpose of this study was to examine the differences in immediate recall of spoken sentences among younger and older adults. Twenty-four young adults and 24 older adults were presented a series of sentences and asked to recall the sentences during a listening span task. Speaking rates were adjusted throughout the study. Results of the study showed that younger adults scored better in recall performance when speaking rate was increased, although the age differences in recall performance were reduced by the presence of linguistic and prosodic cues. Additionally, older adults were also found to add more words to make more meaning-producing reconstructions in recall.

Tjaden, K., & Wilding, G. (2004). Rate and loudness manipulations in dysarthria: Acoustic and perceptual findings. *Journal of Speech, Language, and Hearing Research, 47*, 766-783. doi: 1092-4388/04/4704-0766

The authors of this study compared speaking rate and loudness effects on intelligibility for speakers with dysarthria. Fifteen speakers with dysarthria secondary to Parkinson's disease, 12 speakers with dysarthria secondary to multiple sclerosis, and 15 healthy controls recorded speech samples win habitual, loud, and slow conditions. Each sample was analyzed acoustically and rated perceptually by ten listeners. The loud condition yielded improved intelligibility for the individuals with Parkinson's disease, relative to their habitual and slow conditions. Speakers with multiple sclerosis, however, were more intelligible in the habitual condition. The authors argued that the modest improvement in the Parkinson's disease group and no improvement in the multiple sclerosis group may reflect the relatively good habitual intelligibility for speakers with mild to modest dysarthria.

Turner, G., & Weismer, G. (1993). Characteristics of speaking rate in the dysarthria associated with amyotrophic lateral sclerosis. *Journal of Speech & Hearing Research, 36*(6), 1134-1144.

The purpose of this study was to examine the characteristics of speaking rate in individuals with dysarthria secondary to amyotrophic lateral sclerosis. Nine speakers with amyotrophic lateral sclerosis and nine healthy controls participated in the study. The speakers recorded three speech samples employing three different speaking rates (habitual, twice as fast as habitual, and half as fast as habitual). Dysarthric speakers showed a greater dependence on pause duration and frequency, as compared to articulation rate, when increasing rate.

Walsche, M., Miller, N., Leahy, M., & Murray, A. (2008). Intelligibility of dysarthric speech: Perceptions of speakers and listeners. *International Journal of Language and Communication Disorders, 43*(6), 6333-648. doi: 10.1080/13682820801887117

This study compared speaker and listener perceptions of dysarthric speech and to examine the role of gender and listener experience in speech perception. Twenty speakers with dysarthria, 10 speech-language pathologists, and 20 naïve listeners rated recordings of dysarthric speech. The speakers then rated their perceptions of their own speech. Perceptual differences were then compared. Results of the study showed no significant differences between speaker and listener perceptions of dysarthric speech and no significant differences across gender and listener experience.

Watson, P., & Hughes, D. (2006). The relationship of vocal loudness manipulation to prosodic F_0 and durational variables in healthy adults. *Journal of Speech, Language, and Hearing Research, 49*, 636-644. doi: 1092-4388/06/4903-0636

The purpose of this study was to examine the relation of vocal loudness to specific prosodic variables meant to aid listener comprehension. Ten young, healthy speakers recorded a paragraph using normal loudness, twice-normal loudness, and half-normal loudness. Prosodic cues were measured acoustically for each of the recording conditions. Results of the analysis showed that there was a statistically significant decrease of fundamental frequency and an increase of final-word lengthening from the half-normal loudness condition to the twice-normal loudness condition. The authors argue that results of the study may suggest that when a speaker with dysarthria increases vocal loudness, prosodic cues may also increase and listener understanding may improve.

Whitehill, T., & Ciocca, V. (2000). Perceptual-phonetic predictors of single-word intelligibility: A study of Cantonese dysarthria. *Journal of Speech, Language, and Hearing Research, 43*, 1451-1465. doi: 1092-4388/00/4306-1451

This study examined the perceptual and phonetic characteristics of Cantonese dysarthria. Twenty speakers with dysarthria secondary to cerebral palsy recorded single-words. Twelve healthy listeners then selected the Cantonese character that best corresponded to

the word they heard. Seventeen phonetic contrasts were then measured. Results showed that intelligibility could be predicted with 97% accuracy by five of the six most problematic contrasts. There were no statistically significant differences in intelligibility for gender, age, or type of cerebral palsy.

Wilson, D., & Wharton, T. (2005). Relevance and prosody. *Journal of Pragmatics, 38*(10), 1559-1579. doi: 10.1016/j.prgma.2005.04.012

> In this article, the authors reviewed a collection of research on the interpretation of prosody and its relation to pragmatic theory. The authors focused on four main issues. First, how should the communication of emotions, attitudes, and impressions be analyzed? Second, how might prosodic elements function as "natural" communication? Third, what do prosodic elements encode? Fourth, what light can the study of prosody shed on the place of pragmatics in the architecture of the mind? The authors concluded that the study of both prosody and pragmatics interact and benefit one another.

Yorkston, K. M., & Beukelman, D. R. (1981). Communication efficiency of dysarthric speakers as measured by sentence intelligibility and speaking rate. *Journal of Speech and Hearing Disorders, 46,* 296-301.

> The purpose of this study was to quantify communication efficiency as related to speaking rates and intelligibility scores. Fourteen speakers participated, including 13 speakers with various types of dysarthria and one normal speaker. A panel of judges transcribed and ranked audio recording of each speaker's speech according to the following measures: word and sentence intelligibility, speaking rate, rates of intelligible and unintelligible speech, and a numerical ranking of communication efficiency. The results of the study indicated that speaking rate and speech intelligibility are not closely related.

Yunusova, Y., Weismer, G., Kent, R., & Rusche, N. (2005). Breath-group intelligibility in dysarthria: Characteristics and underlying correlates. *Journal of Speech, Language, and Hearing Research, 48*, 1294-1310. doi: 1092-4388/05/4806-1294

> The purpose of this study was to determine whether within-speaker fluctuations in speech intelligibility occurred among speakers with dysarthria, and if so, which linguistic and acoustic features predicted the variations in intelligibility. Ten speakers with dysarthria secondary to Parkinson's disease and amyotrophic lateral sclerosis and ten healthy controls participated in the study. Each participant recorded a paragraph-length reading passage separated into consecutive breath groups. Sixty listeners rated each speaker's speech intelligibility. Results showed that speakers with dysarthria had fluctuations in speech intelligibility across breath groups. Additionally, speakers with dysarthria produced fewer average words across breath groups and showed decreased articulatory mobility. The authors also concluded that linguistic or acoustic variables that predict across-speaker intelligibility differences may not function the same way to explain intelligibility fluctuations within speakers.

Appendix B—Informed Consent to Participate in a Research Study (speaker)

Introduction
The purpose of this research experiment is to learn more about the intelligibility of disordered speech. You have been invited to participate in the study because you are an individual who has dysarthria, and you are a native English speaker. This experiment is being conducted by Emily Redd, a graduate student in speech-language pathology, under the direction of Christopher Dromey, Ph.D, a professor in the Department of Communication Disorders at Brigham Young University.

Procedure
In this experiment you will be asked to say 50 short sentences into a microphone. The speech recordings will be made in a research lab in the John Taylor Building at Brigham Young University. The session will last approximately 20-30 minutes. You are free to ask questions at any time during the study.

Risks/Discomforts
There are minimal risks for participation in this study.

Benefits
There are no direct benefits to you as a participant; however, it is hoped that through your participation researchers will learn more about the importance of intonation in dysarthric speech.

Confidentiality
All information provided will remain confidential and will only be reported without any identifying information. All data will be kept on a password protected computer in a locked laboratory and only those directly involved with the research will have access to them.

Participation
Participation in this study is voluntary. You are free to withdraw at any time without any effect on your relationship with BYU.

Questions about the Research
If you have questions regarding this study, you may contact Dr. Christopher Dromey at 801/422-6461 or at dromey@byu.edu. If you have any questions regarding your rights as a participant in a research study, you may contact the BYU IRB Administrator, A-285 ASB, Brigham Young University, Provo, Utah 84602 or at 801/422-1461 or irb@byu.edu.

I agree to participate in the research study described above. I confirm that I have read the preceding information and my questions have been answered to my satisfaction. I hereby give my consent for participation as described.

Printed Name:_____ Age:_____

Signature of Participant:_____ Date: _____

Appendix B—Informed Consent to Participate in a Research Study (listener)

Introduction
The purpose of this research experiment is to learn more about the intelligibility of disordered speech. You have been invited to participate in the study because you are a native English speaker with no history of any speech, language, or hearing disorders. This experiment is being conducted by Emily Redd, a graduate student in speech-language pathology, under the direction of Christopher Dromey, Ph.D, a professor in the Department of Communication Disorders at Brigham Young University.

Procedure
In this experiment you will be asked to (1) participate in a standard hearing screening and (2) rate the intelligibility of some speech recordings by typing what you hear and completing a 10-point rating scale. The hearing screening and speech ratings will be conducted in a research lab in the John Taylor Building at Brigham Young University. The session will last approximately 20-30 minutes. You are free to ask questions at any time during testing.

Risks/Discomforts
There are minimal risks for participation in this study.

Benefits
There are no direct benefits to you as a participant; however, it is hoped that through your participation researchers will learn more about factors that influence speech intelligibility.

Confidentiality
All information provided will remain confidential and will only be reported as group data without any identifying information. All data will be kept on a password protected computer in a locked laboratory and only those directly involved with the research will have access to them.

Participation
Participation in this study is voluntary. You are free to withdraw at any time without any effect on your relationship with BYU.

Questions about the Research
If you have questions regarding this study, you may contact Dr. Christopher Dromey at 801/422-6461 or at dromey@byu.edu. If you have any questions regarding your rights as a participant in a research study, you may contact the BYU IRB Administrator, A-285 ASB, Brigham Young University, Provo, Utah 84602 or at 801/422-1461 or irb@byu.edu

I agree to participate in the research study described above. I confirm that I have read the preceding information and my questions have been answered to my satisfaction. I hereby give my consent for participation as described.

Printed Name:_____ Age:_____
Signature of Participant:_____ Date: _____

Appendix C—Speech Recording Stimuli

1. Time stated she should leave that day.
2. Animals often wander across wooded grassy paths.
3. Dogs with shaggy white coats appear fuzzy.
4. They began mixing dangerous materials by beaches.
5. Math instructors always allow pens before testing.
6. Mark buys baby elephants salty, crunchy cashews.
7. Black, wild, furry creatures act rather mysteriously.
8. Old baking books seem cheaper every summer.
9. Rich bankers enjoy small, rustic, summer homes.
10. Giant plastic bracelets do well each season.
11. Children carrying orange dotted scarves seem weird.
12. Wearing red gloves kept John rather happy.
13. Hot, darting rays dance along gray pavement.
14. Martha's friend bakes banana chips all winter.
15. Fast moving turtles never eat after sleeping.
16. Some creative authors try inventing exotic styles.
17. Lonely birds wander along clammy black caves.
18. Jim began milking reptiles almost daily.
19. Chlorine changed his old clothes two tones.
20. Smashing big juicy apples involves great skill.
21. Many baseball jerseys get worn before winter.
22. Tall guys prefer trim, delicate, pale arms
23. Four sleepy puppies snore beside that chair.
24. Big people often have old, noisy trucks.
25. Nice men usually grill better fresh vegetables.
26. Lamb seems juicier broiled using light sauces.
27. She always believes corn smells rather salty.
28. They spilled thin, yellow primer over furniture.
29. Happy dogs relish long baths near evening.
30. Red bricks sink quickly through thick mud.
31. Tall professors love ignoring loud, bothersome nephews.
32. Fat, soft marshmallows become tasty, warm desserts.
33. Bob buys instruments, although rarely purchases keyboards.
34. Defensive men often design mittens when relaxing.
35. Juice or candy won't fix his moods.
36. Tina loves making ham using tangy spices.
37. Package black pens using little silver boxes.
38. Boys never hid near big red cars.
39. Mary drove carelessly every rainy Friday afternoon.
40. Three puppies followed Jim's old, blue bike.
41. Steve seldom forgets dusting old card tables.
42. New watches usually display glowing red digits.
43. Four pink bubbles burst under her wand.

44. Playful orange butterflies climb long, green curtains.
45. Lucy's right sneaker sank through thick slime.
46. Biking past hilly pastures creates lovely screens.
47. Inky dots dance over shimmering new screens.
48. Loud restaurant singers always project harsh attitudes.
49. Spicy cabbage flavored everyone's favorite meat stew.
50. Andrew's blue notebook broke suddenly that morning.