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Effect of rate reduction on speech intelligibility in individuals with dysarthria

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EFFECT OF RATE REDUCTION ON SPEECH INTELLIGIBILITY IN INDIVIDUALS
WITH DYSARTHRIA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Arts

in

The Department of Communication Sciences and Disorders

by
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B.A., University of Louisiana at Monroe, 2006
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ABSTRACT

This study examined how speech rate reduction affects speech intelligibility in speakers with dysarthria associated with diverse neurological conditions. Three speakers with dysarthria were recorded reading a paragraph using conversational and reduced speech rates. The samples of both the conversational and slow rates were digitally edited to include silent pauses at the speakers' natural breaks. The samples were then segmented into breath group utterances. Five samples with the greatest rate reductions from each speaker were used as stimuli, each presented in four rate conditions: conversational, slow, synthesized conversational, and synthesized slow. The listeners rated the intelligibility of 60 samples using direct magnitude estimation (DME), a simple scaling technique used to rate items in comparison to a standard.

Though each of the speakers successfully reduced their rates, none of their intelligibility ratings improved using rate reduction. In fact, the intelligibility of two of the speakers significantly decreased when rate reduction was employed. Analysis of the acoustic vowel space showed some articulatory changes were made by the speakers. Possible reasons for the negative effects of rate reductions are explored along with clinical implications.

INTRODUCTION

Dysarthria is defined as a group of neurological disorders affecting the muscle control necessary for speech movements (Darley, Aronson, & Brown, 1969a, b). Any component of speech production (respiration, phonation, resonance, articulation, and prosody) may be affected by dysarthria. The abnormalities of strength, speed, range, steadiness, tone, and accuracy typically associated with dysarthria are reflected in output of the impaired speech system. Although different speech disturbances are found across dysarthria types, a common feature is reduced speech intelligibility (Duffy, 2005).

Among the various behavioral treatments for dysarthria, modification of speaking rate is reported to be one of the most powerful techniques for improving intelligibility. Rate modification includes both slowing down and speeding up the patient's speech rate, though rate reduction is typically employed (Duffy, 2005). Rate reduction is accomplished when the speaker adjusts articulation time and pause time to reduce their overall speech rate (Tjaden & Wilding, 2011). A variety of strategies are used to slow speech rate, including pacing boards, alphabet boards, hand or finger tapping, delayed auditory feedback, visual feedback, rhythmic cueing, and fluency shaping programs (Duffy, 2005; McHenry, 2003).

Although much focus has been placed on the strategies speakers with dysarthria use to accomplish rate reduction, the mechanism underlying intelligibility improvement associated with reduced speech rate is not clear. A common hypothesis is that a slowed speech rate provides the speaker with more time to attain a variety of articulatory improvements (Duffy, 2005). However, it is unclear whether there is a significant correlation between slowed articulatory rates and improved speech intelligibility (Tjaden & Wilding, 2004). Another possible mechanism for the improvement in intelligibility is the increased processing time that is afforded listeners by

reduced speech rates (Nishio, Tanaka, Sakabibara, & Abe, 2011). It is of interest to better understand the mechanism by which reduced speech rate improves intelligibility on purely theoretical grounds. It is also clinically important in that it would allow further research to determine which clinical population would most benefit from this speech modification.

This study will address the following questions:

1. Does reduced speech rate yield improvement in perceived speech intelligibility in people with dysarthria when compared to a conversational rate?
2. Is there a difference between the effects of natural rate reduction and synthesized rate reduction on intelligibility in people with dysarthria?
3. If there is a difference between natural and synthesized rate reduction, do changes in acoustic vowel space, and thus articulatory modification, explain this difference?

We hypothesize that reduced speech rate will improve perceived speech intelligibility.

We also suggest that natural rate reduction will improve perceived speech intelligibility at a rate greater than or equal to synthesized rate reduction. If natural rate reduction leads to a greater improvement in perceived speech intelligibility, then acoustic parameters, such as acoustic vowel space, should reveal an articulatory mechanism related to the increase of speech intelligibility.

LITERATURE REVIEW

Speech Characteristics of Dysarthria

Speech characteristics of dysarthria vary according to the type of dysarthria (Duffy, 2005). As a group of neurological disorders, dysarthria is typically identified according to five types, each with distinguishing lesion sites and etiologies: flaccid, spastic, ataxic, hypokinetic, hyperkinetic. Each type was identified as part of a classification system (the *Mayo System*) developed from two classic studies by Darley, Aronson, & Brown (1969a, b), in which thirty-second speech samples from 212 speakers with one of seven dysarthria-related diagnoses were studied. The authors also described a mixed type dysarthria which combined flaccid and spastic types. Later, Duffy (1995) added a seventh type, unilateral upper motor neuron dysarthria.

According to the Mayo System, differential diagnosis of dysarthria includes 38 dimensions of speech and voice abnormalities consistent with dysarthria. For example, flaccid dysarthria should exhibit the characteristics of hypernasality, imprecise consonants, breathy voice, and monopitch (Darley et al., 1969b). Notably, the articulatory deficiencies of imprecise consonants and distorted vowels were found to be common across all dysarthria types. This likely serves as the basis for the theory that rate reduction improves intelligibility by providing more time for speakers to attain articulatory targets given that these characteristics have been reported to contribute significantly to the patient's speech intelligibility (Darley et al., 1969a, b).

Speech Intelligibility

Speech Intelligibility refers to the degree to which the listener understands the utterance produced by the speaker (Duffy, 2005). Speech intelligibility is judged on the basis of the acoustic signal, as opposed to comprehensibility, which also incorporates signal-independent information such semantics, syntax, and physical context (Yorkston, Strand, & Kennedy, 1996).

Estimates of speech intelligibility are often used as a measure of speech severity in dysarthria as an index of the extent to which neurological disease affects the speech mechanism. A number of studies have observed change in speech intelligibility within and across multiple speakers with similar and different speech severities (Kim, Kent, & Weismer, 2011).

Though there are several strategies for measuring speech intelligibility, two general categories of measurement exist: subjective and objective. Subjective measures require listeners to assign numerical values to what they have heard in order to quantify their perception of a speaker's intelligibility. Methods such as equal appearing interval scales (EAI) and direct magnitude estimation (DME) have both been used extensively in research involving perceptual phenomena such as speech intelligibility (Weismer, 2007). Objective measures typically involve calculating an intelligibility rating from a listener's orthographic transcriptions of single words or connected speech produced by the speaker (Yorkston et al., 1996). Several standardized, objective measures of intelligibility have been developed, including the Assessment of Intelligibility in Dysarthric Speakers (AIDS), the Sentence Intelligibility Test (SIT), and the Frenchay Dysarthria Assessment (FDA) (Duffy, 2005).

Relatively recently, DME has been introduced as a measure of speech intelligibility, which involves rating each speech stimulus proportionally, or relative to a standard (Weismer & Laures, 2002). DME may be conducted with or without a modulus. In DME with-modulus, the investigator sets a standard speech sample and assigns it a numerical value against which the listener will rate the stimuli. For example, if the investigator chose a speech sample modulus representing middle intelligibility and assigns it a value of 50, the listener will then judge the stimuli relative to that standard. If they judge a stimulus to be half as intelligible as the modulus they would assign it a value of 25 (Kim & Kuo, 2012; Weismer & Laures, 2002).

It has been noted that DME with-modulus presents advantages over both word identification tests and other scaling techniques such as interval scaling (Schiavetti et al., 1981). DME may be more sensitive to nonsegmental contributors to decreased intelligibility, such as voice quality or prosody, than the typical word- or sentence-based percentage intelligibility estimate (Weismer & Laures, 2002). While the listener is constrained to a set spectrum in interval scaling, DME allows the listener to freely rate each stimulus according to a standard (Schiavetti et al., 1981). Most importantly, Schiavetti, Metz, and Sitler (1981) reported that DME is an appropriate scaling procedure for measuring speech intelligibility. By comparing the speech intelligibility DME ratings of 20 speakers with hearing impairment to ratings on the same individuals using interval scaling, he found the construct validity for DME to be greater than for interval scaling of speech intelligibility (Schiavetti et al., 1981). Therefore, for the purposes of this study, DME with-modulus, rather than interval scaling, will be employed for the assessment of speech intelligibility.

Rate Reduction

Effect of rate reduction on intelligibility. As previously stated, rate reduction's most prominent application is improving speech intelligibility. Several studies found rate reduction has a positive effect on speech intelligibility of individuals with dysarthria. Yorkston, Hammen, Beukelman, and Traynor (1990) found that each of four different pacing strategies for reducing speech rate improved sentence intelligibility in four individuals with severe ataxic dysarthria and four individuals with severe hypokinetic dysarthria. Nishio et al. (2011) reported that reducing verbal speed 150-200% with speech-rate conversion software was optimal for improving intelligibility and naturalness in a group of 62 individuals with dysarthria. Hammen, Yorkston,

and Minifie (1994) found that a paced rate reduction technique improved intelligibility in speakers with Parkinson's Disorder (PD).

Other studies, however, have been less conclusive as to the effectiveness of rate reduction, as the effect may differ according to dysarthria type and severity (Duffy, 2005). Van Nuffelen, De Bodt, Vanderwegen, Van de Heyning and Wuyts (2010) found that not all speakers with dysarthria will experience improved intelligibility when using reduced speech rate. Turner, Tjaden, and Weismer (1995) reported that rate manipulation did not uniformly affect intelligibility across a group of nine speakers with amyotrophic lateral sclerosis (ALS). Hammen et al. (1994) also found that synthetic temporal alterations of speech duration and pauses did not improve intelligibility in speakers with PD. When comparing rate and loudness manipulation in a group including individuals with PD and Multiple Sclerosis (MS), Tjaden and Wilding (2004) found that rate reduction did not improve intelligibility for either population. Since the evidence supporting the efficacy of rate reduction has shown mixed results, one of the aims of this study is to contribute to the evidence base of rate reduction's effect on speech intelligibility in speakers with dysarthria.

Mechanisms of rate reduction. Rate reduction is thought to produce a range of benefits for patients with dysarthria. It may provide the speaker with additional time for a full range of articulatory movement, coordination, or linguistic phrasing (Duffy, 2005). Some evidence suggests that rate reduction can reduce spatiotemporal variability (McHenry, 2003), offer a comparatively easy motor goal (Hammen & Torp, 1999), and provide the listener with additional time to process the speech signal (Nishio et al., 2011).

Of these benefits, additional time for speakers to attain articulatory targets is often advanced as the reason rate reduction improves intelligibility (Nishio et al., 2011). Some studies

have linked slowed articulatory rates with articulatory displacements and vocal tract shapes that approximate those of healthy speakers (Adams, Gordon-Hickey, Morlas, & Moore, 1994; Caligiuri, 1989; Turner et al., 1995). Other studies, however, have cast doubt on this link. Tjaden and Wilding's 2004 study found that it is unclear whether slowed articulatory rates are also significantly correlated with improved speech intelligibility. Turner et al.'s (1995) study of speakers with Amyotrophic lateral sclerosis (ALS) reported that even though reduced vowel space accounts for 45% of variance in speech intelligibility, rate manipulation doesn't uniformly affect acoustic vowel space or intelligibility.

Another possible cause for the increase in intelligibility is additional time for the listener to process the speech signal (Nishio et al., 2011). Additional time is created for the listener when the overall duration of the speaker's utterance is increased by the speaker's adjustments of articulation time and pause time (Tjaden & Wilding, 2011). Pauses can be especially important in rate reduction because they carry information about syntactic boundaries, are more modifiable than speech signals, and can make up as much as 30% to 50% of the duration of an utterance (Goldman-Eisler, 1961; Duffy, 2005). In this study we will insert digitally synthesized silent segments into the speech samples in order to isolate the speech signals from the pauses. This will allow us to determine what aspect of rate reduction, articulatory time or pause time, is making a greater contribution to improved speech intelligibility.

METHODS

Experimental Design

This study employed a factorial design. The independent variable was speech rate with four conditions: conversational rate, slow rate, synthetically reduced conversational rate, and synthetically reduced slow rate. The dependent variable was perceptual ratings of speech intelligibility.

Participants

Speakers. This study was reviewed and approved by the Institutional Review Board at Louisiana State University (LSU). The speakers included three individuals with dysarthria ranging in age from 43 to 64. All three speakers reported attending speech therapy and usage of rate reduction in therapy. Speaker profiles are summarized in table 1. Speakers were enrolled according to the following criteria: 1) English as a primary language, 2) diagnosis of adult-onset dysarthria by a professional speech language pathologist, 3) no current diagnosis of other neurological disorders, and 4) no other communicative problems such as hearing disorder or aphasia. Each speaker was recruited from the LSU Speech Language and Hearing Clinic and the greater Baton Rouge area.

Table 1. Description of speakers.

Speaker	Gender	Age	Etiology	Prominent Speech Characteristics
1	M	64	Stroke	Imprecise consonants, slow rate, harsh voice, distorted vowels, monoloudness
2	M	43	Stroke	Hypernasal, monopitch, slow rate, excess loudness variation, imprecise consonants
3	F	58	PD	Normal-to-fast rate, reduced volume, monopitch, monoloudness

Listeners. The listener group included 42 undergraduate students enrolled at LSU. Listeners were enrolled in the study according to the following criteria: 1) English as a primary language, 2) self-reported normal hearing, 3) and little to no self-reported experience with speakers with dysarthria. A short interview was conducted with the listeners to determine these criteria.

Procedures

Recording. A passage consisting of 313 monosyllabic words, known as the Farm Passage, was selected as the stimulus (Crystal & House, 1982). This passage was developed by Crystal and House to be comprised of 553 consonants and 327 vowels in various classes of speech sounds according to their frequency of occurrence in conversational English (see Appendix A). The speech samples were recorded in a double-walled sound booth in the Speech Acoustics Laboratory of the Communication Disorders Department at LSU. An AKG Perception 120 USB microphone, *Praat* software (Boersma & Weenink, 2012), and a Dell OptiPlex 740 were used for the recordings at a sampling rate of 44.1 kHz and with 16-bit quantization. Each speaker was seated approximately one foot from the microphone, which was positioned on the table directly in front of them.

Speakers read the passage under two conditions: a conversational speech rate and a slow speech rate. First, speakers were instructed to read the passage at the same rate they would use in everyday conversation. After completing the passage, the speakers were instructed to read the passage slowly by using a magnitude production (see Appendix B) (Tjaden & Wilding, 2004). Both the instructions and the passage were presented to the speaker on paper printed in size 18

Times New Roman font. The speakers were permitted to take a break, if needed, at any point during the recording.

Editing. In addition to the conversational (A) and slow (B) rate sets previously mentioned, two synthesized sets of speech samples, synthetically reduced conversational rate (C) and synthetically reduced slow rate samples (D), were created using the sound editing software *Audacity* (Audacity Team, 2012). First, the percentages of rate reduction from the conversational rate to the corresponding slow rate were calculated for each set of samples. To create the synthetically reduced conversational rate set, the durations of the conversational rate samples were lengthened to match the percentage of rate reduction in the corresponding slow rate samples. To create the synthetically reduced slow rate set, the durations of the slow rate samples were lengthened by the same percentage as the synthetically reduced conversational rate set (see Figure 1).

In order to synthetically lengthen the samples without distorting the original speech signals (e.g. vowel formant structures, word durations) other than the pause durations, the researcher added silent segments to the natural breaks between the words and sentences. Specific natural breaks were selected by running a silence analysis set to treat audio below 20dB as silence and to find a minimum duration of 0.25 seconds of silence.

Presentation. A total of 60 utterances were prepared to present to the listeners (5 utterances x 3 speakers x 4 conditions). Utterances were selected from the Farm Passage by first segmenting the speakers' conversational rate paragraph into breath groups. For this study, a breath group was defined as a unit of continuous speech produced in a single breath, measured from the start to the end of the speech signal (Wang, Green, Nip, Kent, & Kent, 2010).

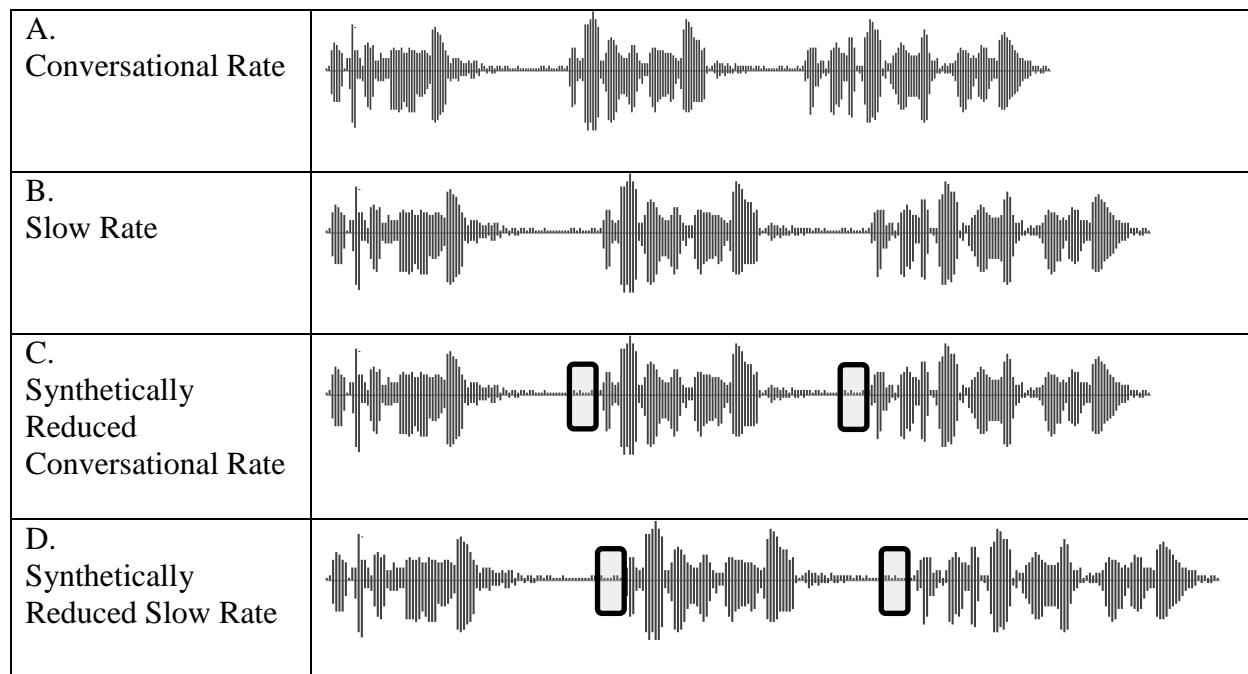


Figure 1. An example of speech stimuli of this study: Waveform A represents a conversational rate sample. Waveform B represents a slow rate sample. Waveform C represents a synthetically reduced conversational rate sample, in which silent segments (i.e. boxed areas) were inserted into waveform A. Waveform D represents a synthetically reduced slow rate, in which silent segments were inserted into waveform B.

The percentage of rate reduction from the conversational sample to the slow sample was then calculated for each utterance. For each speaker, the five utterances with the highest percentages of rate reduction were selected to serve as stimuli (see Appendix C). Listeners were presented the speech samples through a pair of Bose Companion 2 Series II multimedia speakers with a Dell OptiPlex 740 computer in the Speech Acoustics Laboratory of the Communication Disorders Department at LSU. Samples were randomized using a randomization table.

Speech intelligibility was judged by the listeners using direct magnitude estimates (DME) with a modulus of 50 (Weismer & Laures, 2002). A reference sample was subjectively chosen by the researcher to represent the mid-level intelligibility among all the speech samples. After listening to the reference sample, the listeners assigned numerical ratings to the speech samples

as compared to the reference. The reference was reintroduced every five samples to remind the listener of the reference sample. The listeners were given a definition of intelligibility (Duffy, 2005) and instructions on how to judge the speech intelligibility of the samples using DME (see Appendix D).

Analysis

Acoustic analysis. An analysis of changes in acoustic vowel space was conducted to determine if articulatory changes were made from conversational to slow speech rate conditions by each speaker. Knowing whether articulatory changes occurred is important for understanding the method by which the speakers reduced their speaking rates, whether by articulatory changes, increasing pause durations, or a combination of both. If little to no articulatory changes occurred, then rate change would have been primarily accomplished by increasing pause durations. Measures of acoustic vowel space were obtained by identifying the temporal midpoints of F1 and F2 for each of the four corner vowels (/æ, i, a, u/) found within the Farm passage and calculating averages for each speaker.

Reliability. In order to establish inter-rater reliability for perceptual speech intelligibility ratings, the intraclass correlation coefficient (ICC) was calculated. Five percent of the speech samples were represented to four of the listeners in order to establish intra-rater reliability.

RESULTS

Rate Reduction

The speakers in this study were instructed to slow their speaking rates to half of what they would normally use in conversational speech by using a DME technique. Rate reduction, relative to the conversational speech rate, was successfully accomplished by each speaker, but with varying degrees of reduction. Speakers 1 & 2, with dysarthria secondary to stroke, had average rate reductions of 76.74% and 50.51% respectively. Speaker 3, with dysarthria secondary to PD, averaged only 34.97%. This is consistent with other studies where speakers with dysarthria were able to make voluntarily rate reductions for short reading passages (Tjaden & Wilding, 2004; McRae et al., 2002; Turner & Weismer, 1993). Table 2 shows the average speech rates for conversational and slow speech rate conditions in syllables per second and the average percentages of rate reduction from the conversational to slow conditions accomplished by each speaker.

Table 2. Mean speech rates and percent rate reduction.

Speakers	Mean Speech Rates (syl/sec)		Mean Percentage of Rate Reduction (%)
	Conversational	Slow	
1	2.154	1.246	76.74
2	2.417	1.602	50.54
3	4.073	3.04	34.82

Intelligibility Ratings

The results will be reported considering the speakers' speech intelligibility ratings across the four speech rate conditions: conversational (A), slow (B), synthesized conversational (C), and synthesized slow (D). Due to the small sample size, and to allow examinations of the speech intelligibility changes across rate conditions, the results will be presented on a case-by-case basis. Figure 2 shows the mean intelligibility ratings for each speaker across the four conditions.

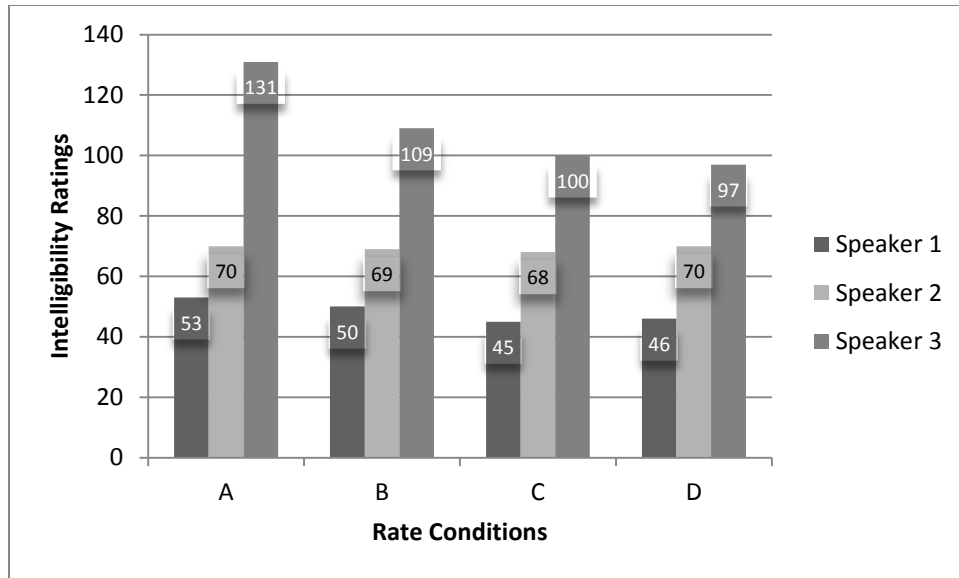


Figure 2. Mean speech intelligibility ratings.

A one-way ANOVA was conducted for each speaker to examine the effect of rate reduction on their speech intelligibility ratings. For Speaker 1, there was a main effect for speech rate condition, $F(3, 839) = 4.584, p < .01$. According to Tukey post hoc testing, condition A samples were not rated significantly higher than condition B samples at an average of 2.105 points ($p = .810$). However, condition A samples were rated significantly higher than condition C samples by an average of 7.138 ($p = .014$) and condition D samples by an average of 6.995 ($p = .017$). Condition B samples were not significantly higher than condition C samples at an average of 5.033 ($p = .144$) or condition D samples at an average of 4.890 ($p = .164$). Condition C samples were rated lower than condition D samples, though not significantly, at an average of $-.143$ ($p = 1.000$).

For Speaker 2, there was no main effect for speech rate condition, $F(3, 839) = .255, p = .858$. For Speaker 3, there was a main effect for speech rate condition, $F(3, 839) = 20.163, p < .01$. According to Tukey post hoc testing, condition A samples were rated significantly higher than condition B samples at an average of 22.576 points ($p < .01$). Condition A samples

were also rated significantly higher than condition C samples by an average of 30.910 ($p < .01$) and condition D samples by an average of 6.995 ($p < .01$). Condition B samples were not significantly higher than condition C samples at an average of 8.333 ($p = .321$) or condition D samples at an average of 11.986 ($p = .068$). Condition C samples were rated higher than condition D samples, though not significantly, at an average of 3.652 ($p = .878$). These results are summarized in Table 3.

Table 3. Speech rate condition paired comparisons (* = significant difference, $p < 0.05$).

Speaker	Condition		Mean Difference	Sig.
1	A	B	2.105	.810
		C*	7.138	.014
		D*	6.995	.017
	B	C	5.033	.144
		D	4.890	.164
	C	D	-.143	1.000
2	A	B	.300	1.000
		C	1.524	.947
		D	-.876	.989
	B	C	1.224	.971
		D	-1.176	.975
	C	D	-2.400	.824
3	A	B*	22.576	.000
		C*	30.910	.000
		D*	6.995	.000
	B	C	8.333	.321
		D	11.986	.068
	C	D	3.652	.878

Acoustic Analysis

Although speech intelligibility ratings did not improve in the slow speech rate (Condition B), acoustic vowel spaces were constructed and compared between conversational speech (Condition A) and slow speech (Condition B) to visually examine any differences in articulatory patterns which are inferred by acoustic F1 and F2 values. Results for Speakers 1 & 2 are shown

in Figures 3 and 4. For Speaker 3, some vowels were not measurable due to weak acoustic signals and poor vocal quality, thus acoustic vowel space was not constructed.

Speaker 1 produced some articulatory changes for /i/ and /u/. Increased tongue height and greater retraction was found for /i/. Tongue placement was lower and more forward for /u/. Speaker 1 produced only minimal changes for /æ/ and /ɑ/, with the tongue more forward for both /æ/ and /ɑ/ but slightly higher for /ɑ/. Speaker 2 produced articulatory changes for all four corner vowels, with the greatest changes for /ɑ/. Tongue placement was higher and more forward for /i/, /u/, and /æ/. For /ɑ/, Speaker 2's tongue placement was higher and more retracted.

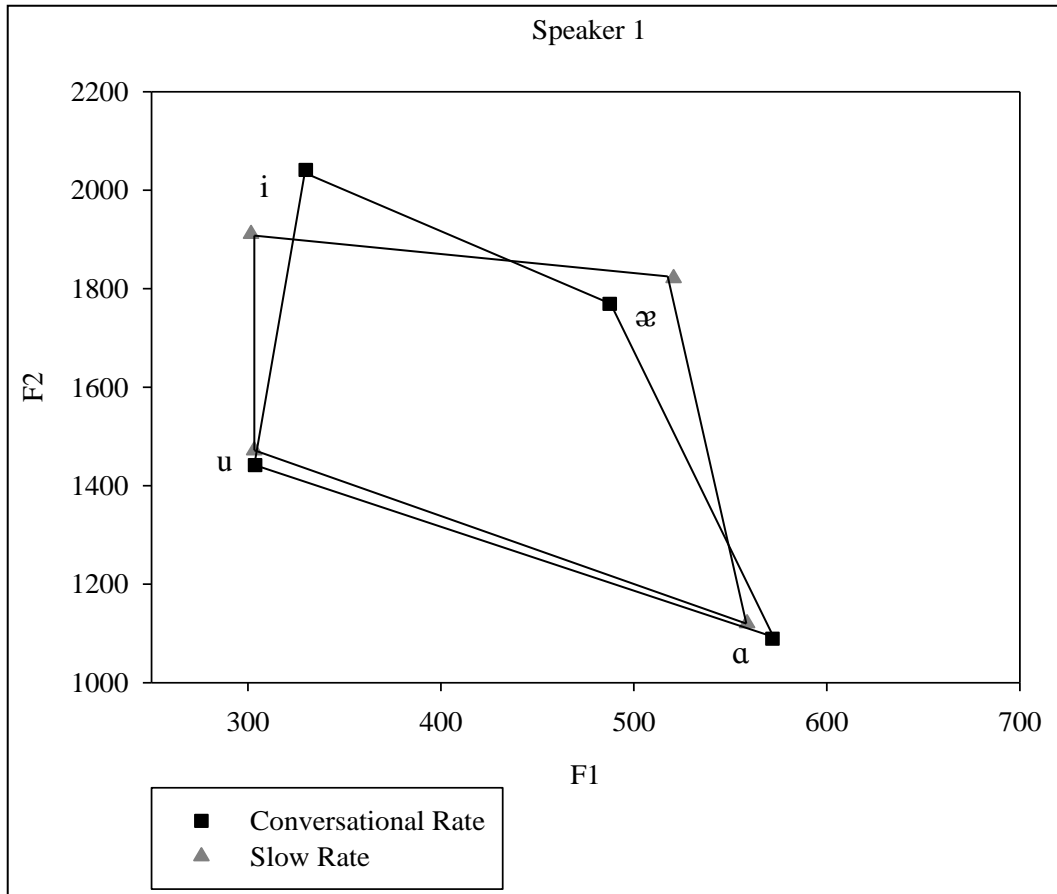


Figure 3. Average acoustic vowel space for Speaker 1 in the conversational and slow speech rate conditions.

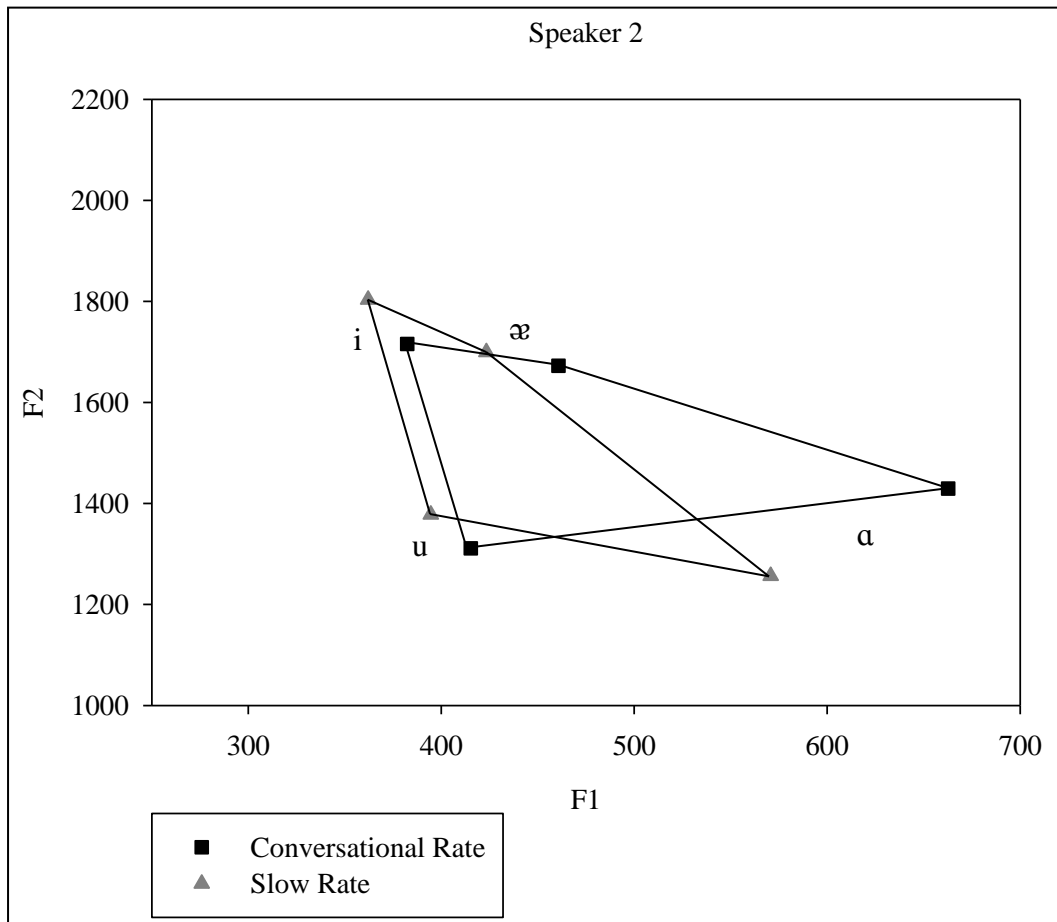


Figure 4. Average acoustic vowel space for Speaker 2 in the conversational and slow speech rate conditions.

Listener Reliability

An intraclass correlation coefficient (ICC) was calculated in SPSS Version 20 (SPSS, Inc., Chicago, IL) to assess inter-rater reliability. The 60 ratings produced by each of the 42 listeners (20 speech samples from 3 speakers) were submitted to a two-way random effects ICC model to determine the consistency of listener ratings. The ICC was .938 ($p < .01$), indicating strong agreement (Sheard, Adams, & Davis, 1991). Intra-rater reliability was calculated for four of the listeners who rated five randomized speech samples twice. The intra-rater correlation coefficient of those listeners was .699, indicating moderate agreement (Kim et al., 2011).

DISCUSSION

Effects of Rate Reduction

Though speech rate manipulation is considered a standard treatment technique for this population, its effect on speech intelligibility and the means by which it affects intelligibility are not well understood. There is conflicting evidence as to both the efficacy of rate reduction and its underlying mechanisms. The main focus of this study, therefore, was to investigate the effects of speech rate reduction on the perceived speech intelligibility of speakers with dysarthria. Sentence level stimuli judged by unfamiliar listeners using DME were chosen in order to provide a more naturalistic, global measure of speech intelligibility.

This results of this study show that rate reduction did not improve the speech intelligibility ratings of the speakers with dysarthria due to stroke or PD. None of the speakers showed improvements in intelligibility when rate reduction was employed, and in some cases speech intelligibility ratings decreased significantly. Speaker 1's intelligibility ratings decreased significantly in the synthesized conditions. The intelligibility ratings for Speaker 2 decreased with rate reduction, though not significantly. Speaker 3's intelligibility ratings decreased significantly in both the slow and synthesized conditions.

Tjaden and Wilding (2004) found similar results in a study of rate and volume manipulation that included 15 speakers with dysarthria secondary to multiple sclerosis (MS) and 12 speakers with dysarthria secondary to PD. Their analysis of scaled intelligibility ratings measured using a DME technique showed that when listeners were presented with an excerpt from a reading passage, there were no significant improvements in intelligibility from habitual to reduced speech rates for either group. However, other studies using sentence level stimuli have reported improvements in speech intelligibility when rate reduction was employed. Yorkston (1990) found improvements in sentence level intelligibility in four speakers with severe

hypokinetic dysarthria and four speakers with severe ataxic dysarthria. Hammen (1994) also found similar improvements in sentence level intelligibility in six speakers with PD.

Possible explanations for the discrepancies between these studies can be found when examining the methods of presenting the stimuli (e.g. the number of presentations to the listeners), the types of listeners/speakers, and the kinds of intelligibility measures. This study and the Tjaden and Wilding study (2004) used unfamiliar listeners who were presented randomized stimuli and asked to rate the intelligibility using DME. Hammen (1994) also used unfamiliar listeners. However, these listeners were presented with two practice sets of five stimuli and were presented with each experimental stimulus three consecutive times in order to transcribe them. This process would likely increase the degree of listener familiarity and may have contributed to the higher intelligibility scores in the slow rate conditions. Yorkston (1990) used judges who were familiar with speakers with dysarthria and who were either certified speech-language pathologists or graduate students in the Department of Speech and Hearing Sciences. These familiar judges were also presented with the entire stimuli set before listening to and rating each stimulus item using a 7-point, equal-appearing interval scale. The results of these studies seem to suggest that additional processing time afforded to listeners may benefit familiar listeners more than unfamiliar ones. However, it would be important to determine whether the additional processing time was attributable to the rate reduction or the repetition of the stimuli.

It is also possible that speakers with specific neuropathologies or severities would be more likely to benefit from rate adjustment strategies. Speakers with severe ataxic or hypokinetic dysarthria, such as those in the Yorkston (1990) study, present with speech characteristics like extremely fast speech or the inability to coordinate speech movements in short times. These may

be more responsive to rate reduction. For example, Kent, Netsell, and Abbs (1979) suggested that increasing speech segment duration may allow ataxic speakers more time to execute cortical control of speech. Also, hypokinetic speakers, such as those with PD, may benefit from reducing their faster-than-normal speech rates (Duffy, 2005). However, Speaker 3 of this study, who presented with dysarthria subsequent to PD, was negatively affected by rate reduction. This may be attributable to the severity of her dysarthria, and her speech rates were not necessarily fast (4.073 syl/sec).

Speaker 3 also had the highest intelligibility in the conversational condition, suggesting that reduced speech rate may have had rather negative effects on speech naturalness especially regarding prosodic features. These are reflected on DME ratings with a greater sensitivity compared to other traditional speech intelligibility ratings such as transcription, where listeners focus more on fine-level articulation features than global phonatory-prosodic aspects of speech production (Kim et al., 2011, Laures & Weismer, 2002). When comparing the impact of rate reduction on naturalness in speakers with dysarthria versus healthy controls, Yorkston (1990) found that rate reduction had a greater negative impact on the naturalness of the healthy speakers. These contrast the findings for Tjaden and Wilding's group with MS. Their rate reduction had less of an effect on the intelligibility of the group with MS than the group with PD., which was reported to reflect the higher habitual speech intelligibility of the group with MS (2004). A high degree of variability in the effects of rate reduction is therefore suggested across severities, intelligibility measures, neuropathology, and speech disturbances of individuals.

Although only a small number of speakers were analyzed in this study, differences were found in the acoustic vowel spaces for Speakers 1 and 2, indicating the speakers made some changes in articulation. However, these articulatory changes do not necessarily indicate a greater

degree of vowel accuracy. It is likely that these changes were not accurate or large enough to have positive effects on the speech intelligibility of the speakers, especially since the speakers were not specifically instructed to focus on articulation or to over-exaggerate their speech movements. Also, the amounts and types of articulatory changes varied between the speakers. This is similar to the finding by Turner, et al (1995) that changes in acoustic vowel space are less systematic across speakers with dysarthria than neurologically intact speakers. In this regard, the results of this study seem to support the possibility that the methods of instructing speakers with dysarthria are important to eliciting greater articulatory changes, and therefore enhancing speech intelligibility. A recent study by Lam, Tjaden & Wilding (2012) reported that different instructions to elicit clear speech result in different degrees of speech clarity and acoustic adjustments. When asked to “over-enunciate,” speakers were rated with the highest speech clarity and the greatest magnitude of acoustic vowel adjustments, compared to when they were asked to produce sentences in habitual, clear, or hearing impaired (speaking as if they were talking to someone with hearing impairment) conditions.

Clinical Application

As this study shows, not all speakers with dysarthria will benefit from rate reduction strategies. When considering the use of rate reduction in therapy, the clinician should take into account three factors: the targeted listeners, the neuropathology/severity of the client’s dysarthria, and the instructions given to the client for rate reduction. If the targeted listeners are people who are familiar with dysarthric speech, such as the client’s family, friends, or therapists, then reduced speech may improve their speech intelligibility. If the client’s goal is to increase or improve public interactions, however, rate reduction may not be a beneficial strategy as it may deteriorate the intelligibility for unfamiliar listeners.

Also, clients with more severe dysarthria, and thus more severely affected speech characteristics, are likely to be better candidates for using speech rate reduction than those with less severe dysarthria. The clinician should also consider how they will instruct the client to reduce their speech rate. The results of this study suggest that specific instructions to improve articulation may be necessary in order to see improvements in intelligibility.

Due to the variance in severity of dysarthric characteristics among individuals, the clinician should always run trial therapy with their client to ensure that this therapy technique will benefit the client. This may be as simple as testing the client's stimulability for rate reduction in conversational speech during their initial assessment. If the clinician decides to use rate reduction for their client, it would be helpful to have a way of determining whether articulatory changes are made. Acoustical analysis of speech samples with computer programs, such as *TF32* (Milenkovic, 2005), is one method that could provide the clinician with measurable data and the client with visual feedback.

Limitations

A primary limitation for this study is the number of speakers that were used to produce the stimuli. An increased number of speakers, with various etiologies and severities, would offer better control for the experiment and allow for more generalizations to be made with the results. Also, intra-rater reliability would have ideally been higher for this experiment.

Future Directions

In this study, the articulatory changes from the conversational to the slow speech conditions made by the speakers were relatively small. In future studies, it would therefore be important to investigate whether more specific instructions for the speakers would improve speech intelligibility in slow rate conditions. Particular focus on articulation when reducing their

speech rates, such as using both over-exaggeration and slow speech, may have more of an effect on speech intelligibility than simple instructions to slow down.

In addition, rate reduction may be successful at the word level rather than the sentence level. A study that looked at the difference between word and sentence level rate reductions may help determine if articulation's role in speech intelligibility. It may show whether speakers could be more successful at making articulatory improvements with the word level over the sentence level. It could also determine whether the smaller cognitive load of interpreting a word versus a sentence would affect the listener's intelligibility judgments.

Conclusion

These results add to the growing evidence that of rate reduction therapy may not be appropriate for all clients with dysarthria, and may in fact hinder intelligibility in some cases. Several factors, such as listener familiarity, severity of the dysarthria, and the methods of rate reduction, may affect the efficacy of rate reduction for improving perceived speech intelligibility. Rate reduction will likely continue to play an important role in the speech therapist's repertoire of strategies for improving speech intelligibility. However, this study shows that it is not a cure all and should be used with due care by the clinician.

REFERENCES

- Adams, E. M., Gordon-Hickey, S., Morlas, H., & Moore, R. (2012). Effect of rate-alteration on speech perception in noise in older adults with normal hearing and hearing impairment. *American Journal of Audiology*. doi: 10.1044/1059-0889(2011/10-0023)
- Audacity Team (2012). Audacity (Version 2.0.1) [Software]. Retrieved from <http://audacity.sourceforge.net/>
- Boersma, P., & Weenink, D. (2012). Praat: doing phonetics by computer (Version 5.3.32) [Software] Retrieved from <http://www.praat.org/>
- Buchner, A., Erdfelder, E., Faul, F., & Lang, A. (2009). G*Power (Version 3.1.2) [Software]. Retrieved from <http://www.psych.uni-duesseldorf.de/abteilungen/aap/gpower3/>
- Caligiuri, M. P. (1989). The influence of speaking rate on articulatory hypokinesia in parkinsonian dysarthria. *Brain and Language*, 36(3), 493-502. doi: 10.1016/0093-934x(89)90080-1
- Crystal, T. H., & House, A. S. (1982). Segmental durations in connected speech signals: Preliminary results. *Journal of the Acoustical Society of America*, 72, 705–716.
- Darley, F. L., Aronson, A. E., & Brown, J. R. (1969). Differential diagnostic patterns of dysarthria. *Journal of Speech, Language, and Hearing Research*, 12(2), 246-269.
- Darley, F. L., Aronson, A. E., & Brown, J. R. (1969). Clusters of deviant speech dimensions in the dysarthrias. *Journal of Speech, Language, and Hearing Research*, 12(3), 462-496.
- Duffy, J. R. (1995). *Motor speech disorders: Substrates, differential diagnosis, and management*. St. Louis, MO: Mosby.
- Duffy, J. R. (2005). *Motor speech disorders: Substrates, differential diagnosis, and management*. St. Louis: Elsevier Mosby.

- Goldman-Eisler, F. (1961). The significance of changes in the rate of articulation. *Language & Speech*, 4(4), 171-174.
- Hammen, V. L., Yorkston, K. M., & Minifie, F. D. (1994). Effects of temporal alterations on speech intelligibility in parkinsonian dysarthria. *Journal of Speech and Hearing Research*, 37(2), 244-253.
- Hammen, V. L., & Torp, J. N. (1999). Effects of speaking rate reduction on segmental characteristics: A preliminary analysis. *Journal of Medical Speech-Language Pathology*, 7, 97.
- Kent, R. D., Netsell, R., & Abbs, J. H. (1979). Acoustic characteristics of dysarthria associated with cerebellar disease. *Journal of Speech and Hearing Research*, 22, 627-648.
- Kim, Y.-J., Kent, R.D., & Weismer, G. (2011). An acoustic study of the relationships among neurological disease, dysarthria type, and severity of dysarthria. *Journal of Speech, Language, and Hearing Research*, 54, 417-429.
- Kim, Y., & Kuo, C. (2012). Effect of level of presentation to listeners on scaled speech intelligibility of speakers with dysarthria. *Folia Phoniatica et Logopaedica*, 64, 26-33.
- Lam, J., Tjaden, K., & Wilding, G. (2012). Acoustics of clear speech: Effect of instruction. *Journal of Speech, Language, and Hearing Research*, 55, 1807-1821. doi: 10.1044/1092-4388(2012/11-0154)
- McHenry, M. A. (2003). The effect of pacing strategies on the variability of speech movement sequences in dysarthria. *Journal of Speech, Language, and Hearing Research*, 46(3), 702-710. doi: 10.1044/1092-4388(2003/055)
- Milenkovic, P. (2005). TF32 [Software]. Retrieved from <http://userpages.chorus.net/cspeech/>
- Nishio, M., Tanaka, Y., Sakabibara, C., & Abe, N. (2011). Effectiveness of speech rate-conversion software for patients with dysarthria. *Journal of Communications Research*, 2(1), 1-12.

- Schiavetti, N., Metz, D. E., & Sitler, R. W. (1981). Construct validity of direct magnitude estimation and interval scaling of speech intelligibility: Evidence from a study of the hearing impaired. *Journal of Speech and Hearing Research, 24*, 441-445.
- Tjaden, K., & Wilding, G. E. (2004). Rate and loudness manipulations in dysarthria: Acoustic and perceptual findings. *Journal of Speech, Language, and Hearing Research, 47*(4), 766-783. doi: 10.1044/1092-4388(2004/058)
- Tjaden, K., & Wilding, G. E. (2011). Speech and pause characteristics associated with voluntary rate reduction in Parkinson's disease and Multiple Sclerosis. *Journal of Communication Disorders, 44*(6), 655-665. doi: 10.1016/j.jcomdis.2011.06.003
- Turner, G. S., Tjaden, K., & Weismer, G. (1995). The influence of speaking rate on vowel space and speech intelligibility for individuals with amyotrophic lateral sclerosis. *Journal of Speech and Hearing Research, 38*(5), 1001-1013.
- Van Nuffelen, G., De Bodt, M., Vanderwegen, J., Van de Heyning, P., & Wuyts, F. (2010). Effect of rate control on speech production and intelligibility in dysarthria. *Folia Phoniatica Logopaedica, 62*, 110-119.
- Wang, Y., Green, J. R., Nip, I., Kent, R. D., & Kent, J. F. (2010). Breath group analysis for reading and spontaneous speech in healthy adults. *Folia Phoniatica et Logopaedica, 62*, 297-302. doi: 10.1159/00316976
- Weismer, G. (2007). *Motor speech disorders*. San Diego: Plural Publishing.
- Weismer, G., & Laures, J. S. (2002). Direct magnitude estimates of speech intelligibility in dysarthria: Effects of a chosen standard. *Journal of Speech, Language, and Hearing Research, 45*(3), 421-433. doi: 10.1044/1092-4388(2002/033)
- Yorkston, K. M., Hammen, V. L., Beukelman, D. R., & Traynor, C. D. (1990). The effect of rate control on the intelligibility and naturalness of dysarthric speech. *Journal of Speech and Hearing Disorders, 55*(3), 550-560.
- Yorkston, K. M., Strand, E. A., & Kennedy, M. R. T. (1996). Comprehensibility of dysarthric speech: Implications for assessment and treatment planning. *American Journal of Speech Language Pathology, 5*(1), 55-66.

APPENDIX A SPEAKER STIMULUS

The Farm Passage (Crystal & House, 1982). John and I went to the farm in June. The sun shone all day, and wind waved the grass in wide fields that ran by the road. Most birds had left on their trek south, but old friends were there to greet us. Piles of wood had been stacked by the door, left there by the man who lives twelve miles down the road. The stove would not last till dawn on what he had cut, so I went and chopped more till the sun set. The sky stays light quite late as far north as that, but I knew it would be a cold night. The car seat was piled high with stuff, but it would have to stay there for the night. It was too far to go to take it all out now. Food was the next thing. John had lit the stove, so I cooked up some hash and beans, which was what was in the cans that I could reach with least work. My box with most of the food was deep in the car, and it was too dark now to dig my way down to it. When served hot, hash and beans taste quite good if it's been a long time since you last ate. We had some bread, of a sort that you find in small stores far from the towns, where the new ways to make bread, and the new types of flour have not yet reached. We had passed such a place on the road, and had stocked up with some things that can't be bought in a town. Things like home baked bread; and real cheese made from cow's milk; jam with real fruit in it; and fresh milk with rich deep cream on top. We shall not have a chance to buy these in the cold months that are to come.

APPENDIX B SPEAKER INSTRUCTIONS

- Read the following paragraph at the same speaking rate you would use in everyday conversation 2 times.
- After you have read the paragraph 2 times with your normal rate, read the paragraph 2 times again but with a slow speaking rate.
- Your everyday conversation speaking rate corresponds to a rate of 10, so your slow rate should be half as fast as your conversational rate, corresponding to a value of 5.

APPENDIX C LISTENER STIMULI

Speaker	Stimulus	Utterances
1	1	...of a sort that you find in small stores far from the towns...
	2	...and had stocked up with some things...
	3	Things like home baked bread...
	4	...and real cheese mad from cow's milk...
	5	...and fresh milk with rich deep cream on top.
2	1	Most birds had left on their trek south...
	2	The stove would not last till dawn...
	3	...but I knew it would be a cold night.
	4	The car seat was piled high...
	5	My box with most of the food...
3	1	The sun shone all day, and wind waved the grass in wide fields by the road.
	2	Most birds had left on their trek south, but old friends were there to greet us.
	3	The car seat was piled high with stuff, but it would have to stay there for the night.
	4	My box with most of the food was deep in the car, and it was too dark now to dig my way down to it.
	5	When served hot, hash and beans taste quite good if it's been a long time since you last ate.

APPENDIX D LISTENER INSTRUCTIONS

- Speech Intelligibility = how well the listener understands the speech produced by the speaker
- Directions:
 - This task will require you to listen to recordings of speakers and judge the speech intelligibility of each sample.
 - A reference sample that represents the midpoint of speech intelligibility will be presented at the beginning and after every 5 samples. The reference sample will have a numerical value of 50.
 - After hearing each recording, write the numerical value that corresponds to your perception of the magnitude of speech intelligibility of the speech sample as compared to the reference. Use any number you wish, except for negative numbers.
 - For example, if you think a sample is twice as intelligible as the reference you would rate it with a value of 100. If you think the sample is half as intelligible as the reference, you would rate it with a value of 25.

APPENDIX E IRB APPROVAL FORM

ACTION ON PROTOCOL APPROVAL REQUEST



Institutional Review Board
Dr. Robert Mathews, Chair
131 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.6792
irb@lsu.edu | lsu.edu/irb

TO: Yunjung Kim
COMD

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: July 16, 2012
RE: IRB# 3296

TITLE: Effect of rate reduction on speech intelligibility in individuals with dysarthria

New Protocol/Modification/Continuation: New Protocol

Review type: Full Expedited **Review date:** 7/17/2012

Risk Factor: Minimal Uncertain Greater Than Minimal

Approved **Disapproved**

Approval Date: 7/17/2012 **Approval Expiration Date:** 7/16/2013

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 150

Protocol Matches Scope of Work in Grant proposal: (if applicable)

By: Robert C. Mathews, Chairman 

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is **CONDITIONAL** on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE:**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at <http://www.lsu.edu/irb>*

VITA

Zachary Hall was raised in Monroe, Louisiana. He graduated from the University of Louisiana at Monroe and earned a Bachelor of Arts degree in Government with a History minor. Directly following graduation, Zachary completed two semesters of law school at the Louisiana State University Paul M. Hebert School of Law. After deciding not to return to law school, Zachary served as a substitute teacher for two years in the East Baton Rouge Public School System. He then enrolled as a master's student in Communication Disorders at Louisiana State University. Zach began his thesis under Dr. Yunjung Kim as a partial fulfillment of the requirements for a Master of Arts degree. Upon graduating, Zach hopes to gain a clinical fellowship position as a school-based speech-pathologist and spend more time with his wife, two children, and two dogs.