The Effect of Two Rate Change Approaches on Speech Movement Patterns

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The Effect of Two Rate Change Approaches on Speech Movement Patterns

Noelle Marie Lewis

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

Master of Science

Christopher Dromey, Chair
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ABSTRACT

The Effect of Two Rate Change Approaches on Speech Movement Patterns

Noelle Marie Lewis
Department of Communication Disorders, BYU
Master of Science

The current study examined the effect of different rate change approaches on speech movement patterns, including increasing and decreasing speaking rate volitionally, as well as with delayed auditory feedback (DAF). There were 10 participants, five male and five female, with a mean age of 25 years. All were typical speakers. Participants spoke the sentence “Don’t fight or pout over a toy car” under slow, fast and DAF speaking conditions. A total of 5 sensors were glued to each participant’s tongue, teeth, and lips. NDI Wave electromagnetic articulography recorded the articulatory movements from these sensors as the participants spoke. Metrics for the individual movement strokes, or articulatory gestures, were calculated based on the movement speed of the articulators during the target utterance. Ten tokens of the target utterance were analyzed for stroke count, stroke speed, duration, and hull area. Vertical movements of the tongue, jaw, lips, and lip aperture were used to calculate the spatiotemporal index to assess variability in speech movements across 10 sentence repetitions. Statistical analysis revealed that articulatory patterns changed significantly in slower speech. A speaker’s efforts to naturally decrease speech rate affected articulation patterns more than did the fast and DAF conditions. Findings from this study can be used as a foundation for future studies with dysarthric individuals, which may increase our understanding of mechanisms of change in the remediation of disordered speech.

Keywords: rate modification, dysarthria, delayed auditory feedback, natural rate control, spatiotemporal index
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I am also grateful for the genuine friendship and love from my cohort, which has strengthened and encouraged me throughout this journey. Special thanks to Amelia Jackson, whose example and camaraderie supported me through data collection and paved a smooth path for analysis and data interpretation. Additionally, I’d like to acknowledge and thank my thesis committee members, Dr. Katy Cabbage and Dr. Tyson Harmon, for their expertise, insights, and support.

Lastly, I owe the utmost appreciation to Dr. Dromey, my thesis chair, for his scholarly expertise, guided mentorship, and invaluable feedback. He made a seemingly insurmountable task possible. I could not have accomplished this without his patient advisement, persistent reassurance, and wealth of knowledge.
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DESCRIPTION OF THESIS STRUCTURE AND CONTENT

This thesis, *The Effect of Two Rate Change Approaches on Speech Movement Patterns*, is composed in a hybrid format. The thesis is recounted as a journal article and corresponds to length and style requirements for submitting research articles to journals of communication disorders. The introductory pages of the thesis indicate requirements for a university submission to Brigham Young University. The literature review is included in Appendix A. The consent document approved by the Institutional Review Board is included in Appendix B.
Introduction

Speech is a unique, multifaceted, motor activity engaging nearly one hundred muscles. It allows individuals the ability to communicate thoughts and emotions. The production of a spoken message requires the ability to form a thought, plan how to express that idea, and then ultimately verbalize it. First, the central and peripheral nervous systems contribute to the production of an acoustic signal by activating the respiratory, phonatory, resonatory, and articulatory muscles. These muscle contractions and movements are often referred to as neuromuscular execution (Duffy, 2013). Most individuals produce speech with automaticity and minimal effort. However, a neurological disease can negatively affect the complex process of producing speech. Dysarthria is a neurological speech disorder that negatively impacts the production of speech. The underlying condition may affect the central and/or peripheral nervous systems, resulting in weakness, spasticity, or incoordination of muscle movements in speech production (Duffy, 2013).

One of the main purposes of speech intervention for people with dysarthria is to improve their intelligibility and increase the effectiveness of communication. Intelligibility is the degree to which a person is understood by a listener. The physiological capacity to produce speech can be refined by improving the function of the affected speech subsystems. This approach emphasizes physiologic restoration or compensation for speakers’ impairments in respiration, phonation, resonance, and articulation. For example, velopharyngeal or respiratory dysfunction can be identified as one physiologic cause of decreased intelligibility. A behavioral focus on articulation is a strategy that has traditionally been viewed as a major part of dysarthria treatment for many patients (Yorkston et al., 1990). Although the goal of treatment efforts is to improve the accuracy of sound production, it is sometimes accomplished by focusing on functions other
than those directly related to place and manner of articulation. For example, articulation can improve with louder phonation, even when no attention is directed to speech movements. In a study by Dromey and Ramig (1998), articulatory movements were examined, and it was found that loudness and rate control led to altered articulatory movement patterns in typical speakers. The current study is designed to examine the effect of rate adjustment on articulatory movement patterns in typical speakers. Without understanding typical speakers’ responses to rate adjustments, we cannot be certain if significant differences in disordered speakers’ performance are disease or treatment related. Before examining such patterns in dysarthric individuals, we must first develop a knowledge of how the speech system operates in neurotypical speakers under normal conditions.

The capacity to communicate effectively can be assessed through measures of intelligibility and efficiency. In individuals with dysarthria, the level of intelligibility depends on a combination of the impaired speech system and any compensatory strategies used by the individual to improve production. Efficiency refers to the rate at which intelligible information is conveyed (Duffy, 2013). For example, some individuals with dysarthria secondary to Parkinson’s disease have rapid speech rates but are highly unintelligible, which causes them to be inefficient in communicating their thoughts (Hammen & Yorkston, 1996). The efficiency is lower in a speaker with moderately reduced intelligibility and a slow rate than someone with comparable intelligibility and a normal rate (Dagenais et al., 2006). Using supplemental strategies such as slow rate or pausing, some individuals can convey messages that are highly intelligible but time consuming. Intelligibility and efficiency contribute to clear and purposeful communication in speakers with dysarthria.
In dysarthric speech, rate control has been suggested as the most adaptable variable for improving intelligibility (Van Nuffelen et al., 2009). An individual with dysarthria can increase coordination and precision of speech movements by slowing the rate of speech (Blanchet & Snyder, 2010). Decreased rate may produce more distinct phonemes by allowing additional time for articulatory movements. Several studies have demonstrated a connection between speech rate and kinematic measures of articulation. Yorkston et al. (2007) examined 17 dysarthria studies researching outcomes of decreased rate of speech and determined that the results of these studies largely established a correlation between a slower-than-habitual rate and increased articulation accuracy, thus improving overall intelligibility. In speakers with dysarthria secondary to Parkinson’s Disease (PD), lip movements were found to be unimpaired at slower speech rates, but these movements decreased as speech rates increased (Caligiuri, 1989). Furthermore, a reduction of speech rate allows the speaker to increase respiratory support, which may result in greater communicative effectiveness (Hammen & Yorkston, 1996). Additionally, slow rate of speech may also provide the listeners more time to process what they are hearing, increasing the speaker’s intelligibility (Yorkston et al., 1990). The results of these studies imply that rate control has a positive influence on the intelligibility of individuals with dysarthria.

Controlling the rate of speech has been found in clinical studies to be a useful intervention method to increase intelligibility in dysarthric speakers (Tjaden et al., 2014). Speakers can repeat, paraphrase, increase loudness or change their rate. Rate reduction is the method often used by neurotypical speakers when one encounters a breakdown in conversation or when one desires to increase the clarity of a message. People with dysarthria will often self-regulate their rate of speech, depending on the situation. The clinician can provide supplemental cues (e.g., visual reminders, audio recording, finger tapping, metronome, and choral speech) to
assist the speaker with dysarthria in speaking at the best rate (Duffy, 2013). When applying the strategy of rate reduction, one study showed an average increase in intelligibility of 26% for 8 speakers with ataxic and hypokinetic dysarthria (Yorkston et al., 1990). Hammen and Yorkston (1996) analyzed the effects of different speech changes on the overall intelligibility of dysarthric speech using three synthetic alterations (pause altered, speech duration altered, and pause and speech duration altered). The effect on intelligibility of each synthetic alteration was unremarkable and the resulting speech was no more intelligible than speech at a habitual rate. Dagenais et al. (2006) further reinforced this finding in a study where dysarthric speech intelligibility was unaffected across all digitally altered speech rates. Although there is strong evidence in favor of the effectiveness of rate control for improving intelligibility, therapy should be individualized to ensure appropriateness for each client. Thus, slowing down speech as it is produced is more beneficial than synthetically altering a recording to simulate slower speech.

Rate reduction strategies reported in the literature often involve the use of a pacing board, alphabet board, tapping a finger, or metered beats (such as from a metronome) to decrease speech rate (Blanchet & Snyder, 2010). These approaches are called speech supplemental strategies; they are usually selected and tailored by the clinician. Mildly impaired dysarthric speakers tend to use less structured pacing methods to reduce rate.

Natural rate control methods (speaking more slowly or quickly upon request) appear to have a wide-ranging effect on intelligibility. Magnitude estimation, a natural rate control approach, is often used as a perceptual scaling method in studies of linguistics and speech disorders. It allows the participants to produce a baseline utterance at their typical rate of speech and then make perceptual judgements on rate without external cues or support. For example, magnitude estimation was employed in a study by Tjaden et al. (2014) to evoke changes in
loudness, clarity, and rate in speakers with Parkinson’s disease and multiple sclerosis. For the rate control portion, the habitual condition was elicited by having each participant read a series of sentences in their typical manner of speaking. Participants were then asked to read the sentences at twice the rate of their typical speech for the fast condition and half the rate of their typical speech for the slow condition. However, this study revealed that voluntary reduction of rate did not result in significant increases in intelligibility (Tjaden et al., 2014). Another similar study examined speakers with amyotrophic lateral sclerosis and found that 4 of the 9 speakers had increased intelligibility when using naturally reduced rates (Turner et al., 1995). Although several findings indicate that such methods can be beneficial, substantial evidence is lacking in long term carry-over and the success of rate reduction techniques in speakers with dysarthria (Blanchet & Snyder, 2010; Hammen & Yorkston, 1996; Van Nuffelen et al., 2009; Yorkston et al., 1990). Furthermore, the association between speech rate reduction and intelligibility can be ambiguous (Knowles et al., 2021; Van Nuffelen et al., 2009).

Delayed auditory feedback (DAF) is an alternative approach to the conventional rate control methods that are used to assist in reducing speaking rate. Originally, DAF was applied in the treatment of individuals who stutter. A device is worn in which the speaker hears their speech delayed while continuing to speak. A short delay (usually between 50-200 milliseconds) is introduced into the speech signal that is sent to the speaker’s ears, similar to an echo. Typical speakers involuntarily slow down, experience disfluencies in speech, and decrease articulation accuracy in response to this atypical, delayed auditory feedback (Chon et al., 2013). Synthetic disturbance of typical auditory feedback, seen in DAF, causes disfluent speech in normal speakers’ voices (Stuart et al., 2002). DAF leads to changes in intonation, segmental, and
Research has shown positive outcomes in the application of delayed auditory feedback to improve intelligibility in some patients with dysarthria. One study examined 11 speakers with dysarthria secondary to PD who used delayed auditory feedback. Two speakers displayed a substantial improvement in intelligibility that was sustained for 24 months after initial treatment. The drawback to the treatment was the requirement of a portable body-worn DAF device, because the speakers only saw benefits when DAF was in use (Downie et al., 1981). Another study revealed that reduced speech rates during DAF use were associated with improvements in speech intelligibility for moderate to severe dysarthria in speakers with PD. However, DAF for mild dysarthria in speakers with PD revealed a decrease in overall intelligibility (Rousseau & Watts, 2002). Outcomes from these studies on DAF suggest that the degree of impairment from dysarthria should be considered when predicting which speakers are most likely to benefit from this rate reduction method. Individual variability in response to auditory feedback in terms of changes in formant frequencies or fundamental frequency, speech rate, and speech disruptions is not well understood, but could hold relevant information concerning whether there are distinct differences among individuals in dependence on auditory feedback. Additional research is needed in this area.

Articulatory movement patterns are usually different in speakers with dysarthria compared to typical individuals (Adams et al., 1993). In order to better determine which cueing modalities improve intelligibility, it is important to develop a greater understanding of articulatory movement patterns when speech rate is increased or decreased. To do so, we must first identify typical speakers’ responses. Dysarthric speech causes a disruption to the
articulatory patterns, distorting the acoustic signal and resulting in unnatural or unintelligible speech. Therefore, kinematic studies of the movement of the articulators (lips, tongue, jaw) aim to reveal how dysarthria disturbs the typical pattern of articulation (Dromey & Ramig, 1998; Weismer et al., 2000). Measures of articulatory patterns in these studies were used to better understand how articulation is influenced by rate and vocal intensity in typical speakers. An understanding of both typical speech patterns and those of dysarthric individuals is crucial to accurately analyze change in response to cueing modalities. Research that includes kinematic measures of articular movement and coordination can increase clinicians' ability to differentiate between typical responses, due to cueing modalities, and those that result from the variability of dysarthric speech. In turn, individualized cueing approaches for patients with dysarthria can be developed.

Individuals with dysarthria often experience reduced speech intelligibility because of a disturbance in the neuromuscular control of speech. As mentioned, it is still unclear how various rate control methods lead to benefits for some speakers with dysarthria and not others. Further research is needed to provide evidence of the efficacy of cueing strategies on the rate, articulatory movement, and naturalness of speech. The purpose of the current study was to examine the effects of delayed auditory feedback and self-adjusted speech rates on articulatory movements in individuals with typical speech. Although applied to typical speakers, the rate adjustment approaches were created for the treatment of dysarthric individuals.

This study is a basic science investigation; its purpose is to add to the currently available knowledge in articulatory kinematics. Previous studies of rate control have been dependent on auditory perceptual analyses. This study provides kinematic data on rate control methods and its impact on articulation that is not currently available from previous studies.
Method

The current study was part of a larger research effort. In addition to the speaking conditions described below, other data were collected on the same day from these participants and used in other research projects, which are not included in the present report.

Participants

Speech samples were provided by 12 native English speakers with no history of speech, language, or hearing impairment. Five women and seven men were recruited from the Brigham Young University community and surrounding areas. Each participant signed a consent form (approved by the BYU Institutional Review Board) indicating willingness to participate in the research study. The recordings from two male participants were not usable for analysis due to equipment failure during the recording session, resulting in five female and five male participants. The mean age of male participants was 27 and the mean age of female participants was 23.

Instrumentation

The speakers were seated in a sound booth while their speech was being recorded with an AKG C2000B condenser microphone. A 30 cm mouth to microphone distance was maintained throughout the data collection. A calibration factor for the microphone was determined by recording a calibration tone at 50 cm from the microphone in dB SPL. Articulatory kinematics of each participant were recorded using the NDI Wave electromagnetic articulograph (Northern Digital Inc., Waterloo, Ontario, Canada). Kinematic data were recorded on seven channels. The first two channels carried the signals from a reference sensor, glued to eyeglass frames without lenses worn by the participants throughout the study; this served as the origin of the coordinate system for the other sensors. Five additional channels of data were collected by attaching 3 mm
sensor coils at midline to the following articulators: vermilion border of the upper lip (UL),
vermillion border of the lower lip (LL), front of tongue (TF), middle of tongue (TM), and
mandibular central incisors to measure jaw movement (J). The sensor coils were adhered with
cyanoacrylate adhesive to the articulators. As a barrier to protect the tooth enamel, Stomahesive
was first attached to the mandibular central incisors with the sensor subsequently adhered to that.
Sensors recorded x, y, and z positions of the articulators in real time through the Wavefront
system to a computer positioned outside the sound booth. Movement data were digitized at a rate
of 100 Hz and the audio signal sampling rate was 22,050 Hz.

**Speech Stimuli**

Articulatory movements were recorded as the participant spoke four test sentences (see
Table 1). The set of 4 sentences was spoken 10 times under each testing condition. The sentence
stimuli were designed to elicit four phonetic targets, including bilabial or alveolar consonants
and diphthongs or corner vowels. Although each participant spoke all four target sentences, only
one sentence, “Don’t fight or pout over a toy car”, was analyzed and reported in this study. The
fast and slow rate conditions for the recordings were elicited by having the participant speak the
sentences for what they estimated to be half and twice the duration of their habitual productions
of the sentences. The participant practiced producing the sentences under each condition before
the recordings were made.
Table 1

*Sentence Stimuli and Phonetic Targets*

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<td>The blue spot is on the black key again.</td>
<td>Corner vowels</td>
</tr>
<tr>
<td>Don’t fight or pout over a toy car.</td>
<td>Diphthongs</td>
</tr>
<tr>
<td>Buy a bag of big red apples.</td>
<td>Bilabials</td>
</tr>
<tr>
<td>It’s not a bad day today.</td>
<td>Alveolars</td>
</tr>
</tbody>
</table>

**Procedure**

Once the sensors were attached to the articulators, participants were instructed to engage in conversational speech for 10 minutes. This allowed for adaptation to the tracking sensors in and around the mouth, minimizing the likelihood of speech changes due to practice effects during data collection (Dromey et al., 2018). Following the adaptation period, participants were instructed to read the speech stimuli using their typical speech rate, pitch, and loudness levels. This recording served as each participant’s baseline for subsequent stimulus recordings. Participants were asked to produce the speech stimuli under three rate cueing conditions: magnitude estimation of twice their habitual rate or at what they judged to be twice their normal rate of speech (fast condition), magnitude estimation of half their habitual rate or half their normal rate of speech (slow condition), and while experiencing delayed auditory feedback (DAF). The order in which cueing conditions were applied was randomized for each participant. Within each condition, the order of the sentences remained the same. For the magnitude estimation conditions, the researcher instructed the participant to “speak about twice as fast as you normally would,” and to “speak about half as fast as you normally would.” For the DAF condition, the Fonate DAF - Stuttering Help app was used, set to delay a participant’s speech
signal by 150 ms. Participants wore headphones relaying the speech signal at a comfortable listening level.

**Kinematic Analysis**

Measures of the spatiotemporal index (STI) for each articulator were computed (Smith et al., 1995), as well as measures of articulatory strokes (Tasko & Westbury, 2002). A custom Matlab application was used to compute these measures from the segmented kinematic records.

**Segmentation**

Dependent measures consisted of separate tokens for analysis derived from the kinematic recording of each subject. To begin the extraction of tokens, it was first roughly segmented into ten separate utterances of the target sentence, “Don’t fight or pout over a toy car” using a custom Matlab (Version 2019b) application (See Figure 1). Ten utterances could not be obtained for subject F1 under the slow conditions due to intermittent equipment failure.

An additional custom Matlab (Version 2019b) application was used to finely segment each roughly segmented file. The sentence, “Don’t fight or pout over a toy car” was finely segmented beginning with the diphthong /aɪ/ in the word “fight” (tongue front upward vertical velocity peak) and ending with the diphthong /ɔɪ/ in the word “toy” (upward velocity peak; see Figure 2).
Figure 1

Rough Segmentation of Kinematic Files

Figure 2

Fine Segmentation of Kinematic Files

**Stroke Metrics**

Stroke measures were analyzed with a custom Matlab (Version 2019b) application for each utterance using 6 kinematic data metrics including stroke count (total number of articulatory strokes), onset speed (mm/s), peak speed (mm/s), mean speed (mm/s), stroke distance (mm), stroke duration (ms), utterance duration (ms), hull area (mm²), and lip aperture. A speed record was calculated from the displacement of the articulators, alternating minima and
maxima in the X and Y planes. This resulted in the Euclidean distance or the length of a segment between two points in the kinematic recording. Throughout the utterance, the lip aperture was measured for distance between the upper lip and lower lip. The hull area refers to the area in \( \text{mm}^2 \) included in the vertical and horizontal directions of all articulatory movements of a sensor during the target sentence. Kinematic stroke metrics provide information about the movement of articulators in continuous speech. Unlike customary point measures, which rely on single movements for a specific syllable or phoneme, stroke metrics offer a global picture of the speech system movements averaged over entire utterances.

**Spatiotemporal Index**

Ten tokens were analyzed for Spatiotemporal Index (STI) from the finely segmented target sentence (diphongs /aɪ/ to /ɒɪ/). STI measures speech pattern variability across multiple sentence repetitions after time and amplitude normalization (Smith et al., 1995). STI was computed for the vertical movements of the tongue mid, tongue front, jaw, lower lip, and upper lip plus the lip aperture.

**Statistical Analysis**

The focus of this study was a comparison of articulation patterns in the habitual condition and the three rate control conditions. A repeated measures ANOVA was conducted to test within-subject effects for the differences in the dependent variables across the rate conditions. Concurrent contrasts were used to determine which rate conditions differed from the habitual speech condition. All statistics were computed with SPSS version 27.

**Results**

The focus of the present report was a comparison of articulation patterns in the typical condition with those in the DAF, slow, and fast conditions. The descriptive statistics are reported
in Tables 2 and 7. The main effects from the repeated measures ANOVA testing are reported in Tables 3 and 8 and contrast analyses of differences between typical speech and the other conditions are reported in Tables 4, 5, 6, 9, and 10. Figures 3, 4, and 5 are an illustrative example of the changes found in stroke count, peak speed, and hull area and were generated using values from the movement of the articulators in the typical, DAF, slow, and fast conditions. Significant changes in the dependent measures across the four speaking conditions are reported below.

**Stroke Measures**

**Stroke Count**

The repeated measures ANOVA revealed a significant main effect of rate on stroke count for all the articulators (see Table 3). For the DAF condition, concurrent contrast results revealed that the stroke count did not change significantly for any articulators compared with the typical condition. Stroke counts increased significantly in the slow speech condition for tongue mid, jaw, upper lip, and lower lip (see Table 6 and Figure 3). The stroke count decreased significantly for the upper lip only in the fast speech condition (see Table 7 and Figure 3). Stroke count did not change significantly for the tongue front in any of the conditions.

**Onset Speed**

There was a main effect of rate condition on onset speed for the tongue front, upper lip, and lower lip (see Table 3). For the DAF condition, concurrent contrast results revealed that the onset speed changed significantly for tongue mid only. Onset speeds decreased significantly in the slow speech condition for tongue mid and tongue front. The onset speed increased significantly for the lower lip only in the fast speech condition (See Tables 2, 3, 4, 5, and 6). Onset speed did not change significantly for the jaw and upper lip.
**Peak Speed**

There was a main effect of rate condition on peak speed for all the articulators (see Table 3). For the DAF condition, concurrent contrast results revealed that the peak speed decreased significantly for tongue mid only. Peak speeds decreased significantly in the slow speech condition for tongue mid, tongue front, and upper lip. The peak speed increased significantly for the lower lip only in the fast speech condition (See Tables 2, 3, 4, 5, 6 and Figure 4). Peak speed did not change significantly for the jaw.

**Mean Speed**

There was a main effect of rate condition on mean speed for all the articulators. For the DAF condition, concurrent contrast results revealed that the mean speed decreased significantly for tongue mid only. Mean speeds decreased significantly in the slow speech condition for tongue mid, tongue front, and upper lip. The mean speed increased significantly for the lower lip only in the fast speech condition (See Tables 2, 4, 5, and 6). Mean speed did not change significantly for the jaw.

**Stroke Distance**

There was a no main effect of rate condition on stroke distance.

**Stroke Duration**

There was a main effect of rate condition on stroke duration for all articulators. For the DAF condition, concurrent contrasts results revealed that the stroke duration did not change significantly for any articulators. Stroke durations increased significantly in the slow speech condition for the tongue mid only. The stroke duration decreased significantly for the tongue mid, jaw, and lower lip in the fast speech condition (See Tables 2, 4, 5, and 6). Stroke duration did not change significantly for the tongue front and upper lip.
**Utterance Duration**

There was a main effect of rate condition on utterance duration. For the DAF condition, concurrent contrasts results revealed that the utterance duration did not change significantly. Utterance duration increased significantly in the slow and decreased significantly in the fast speech conditions (See Tables 2, 4, 5, and 6).

**Hull Area**

There was a main effect of rate condition on hull area for tongue mid only. For the DAF condition, concurrent contrasts results revealed that the hull area did not change significantly for any articulators. Hull areas increased significantly for the tongue mid in the slow and decreased significantly in the fast speech conditions (See Tables 2, 3, 4, 5 and Figure 5). Hull area did not change significantly for the tongue front, jaw, upper lip, and lower lip.
Table 2

Means and Standard Deviations of Stroke Measures for Typical, DAF, Slow, and Fast Conditions

<table>
<thead>
<tr>
<th>Measure</th>
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<th>SD</th>
<th>DAF M</th>
<th>SD</th>
<th>Slow M</th>
<th>SD</th>
<th>Fast M</th>
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Typical DAF Slow Fast

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<th>SD</th>
<th>DAF M</th>
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<th>Slow M</th>
<th>SD</th>
<th>Fast M</th>
<th>SD</th>
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Utterance Duration (ms)

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<th>SD</th>
<th>DAF M</th>
<th>SD</th>
<th>Slow M</th>
<th>SD</th>
<th>Fast M</th>
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<td>111.22</td>
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</table>

Note. TF = tongue front, TM = tongue mid, J = jaw, LL = lower lip, UL = upper lip, ALL = all articulators, TYP = typical, DAF = delayed auditory feedback, Slow = magnitude estimation half typical speed, Fast = magnitude estimation twice typical speed.

Figure 3

Means and Standard Deviations of Stroke Count for Tongue Mid Under Typical, DAF, Slow, and Fast Conditions
Figure 4

*Means and Standard Deviations of Peak Speed for Tongue Mid Under Typical, DAF, Slow, and Fast Conditions*

![Graph showing peak speed for typical, DAF, slow, and fast conditions.](image)

Figure 5

*Means and Standard Deviations of Hull Area for Tongue Mid Under Typical, DAF, Slow, and Fast Conditions*

![Graph showing hull area for typical, DAF, slow, and fast conditions.](image)
### Table 3

*ANOVA Main Effects of Rate Condition on Stroke Measures*

<table>
<thead>
<tr>
<th>Articulator</th>
<th>Measure</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>ES</th>
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*Note.* TF = tongue front, TM = tongue mid, J = jaw, LL = lower lip, UL = upper lip, ALL = all articulators.
### Table 4

*Concurrent Contrast Results for Stroke Measures in DAF Versus Typical Speech Rate*

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*Note.* DAF = delayed auditory feedback, TM = tongue mid.

### Table 5

*Concurrent Contrast Results for Stroke Measures in Slow Speech Versus Typical Speech Rate*

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<td>J</td>
<td>Stroke Count</td>
<td>1,8</td>
<td>20.511</td>
<td>.002</td>
<td>.719</td>
</tr>
<tr>
<td>UL</td>
<td>Stroke Count</td>
<td>1,8</td>
<td>22.843</td>
<td>.001</td>
<td>.741</td>
</tr>
<tr>
<td></td>
<td>Peak Speed</td>
<td>1,8</td>
<td>16.223</td>
<td>.004</td>
<td>.67</td>
</tr>
<tr>
<td></td>
<td>Mean Speed</td>
<td>1,8</td>
<td>11.240</td>
<td>.001</td>
<td>.584</td>
</tr>
<tr>
<td>LL</td>
<td>Stroke Count</td>
<td>1,8</td>
<td>20.868</td>
<td>.002</td>
<td>.723</td>
</tr>
<tr>
<td>ALL</td>
<td>Utterance Duration</td>
<td>1,8</td>
<td>22.356</td>
<td>.001</td>
<td>.736</td>
</tr>
</tbody>
</table>

*Note.* TF = tongue front, TM = tongue mid, J = jaw, LL = lower lip, UL = upper lip, ALL = all articulators.
Table 6

Concurrent Contrast Results for the Stroke Measures in Fast Speech Condition Versus Typical Speech Rate

<table>
<thead>
<tr>
<th>Articulator</th>
<th>Measure</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>Stroke Duration</td>
<td>1,8</td>
<td>12.697</td>
<td>.007</td>
<td>.613</td>
</tr>
<tr>
<td></td>
<td>Hull Area</td>
<td>1,8</td>
<td>14.640</td>
<td>.005</td>
<td>.647</td>
</tr>
<tr>
<td>J</td>
<td>Stroke Duration</td>
<td>1,8</td>
<td>18.500</td>
<td>.003</td>
<td>.698</td>
</tr>
<tr>
<td>UL</td>
<td>Stroke Count</td>
<td>1,8</td>
<td>12.452</td>
<td>.008</td>
<td>.609</td>
</tr>
<tr>
<td>LL</td>
<td>Onset Speed</td>
<td>1,8</td>
<td>27.296</td>
<td>.001</td>
<td>.773</td>
</tr>
<tr>
<td></td>
<td>Peak Speed</td>
<td>1,8</td>
<td>17.995</td>
<td>.003</td>
<td>.692</td>
</tr>
<tr>
<td></td>
<td>Mean Speed</td>
<td>1,8</td>
<td>18.804</td>
<td>.002</td>
<td>.702</td>
</tr>
<tr>
<td></td>
<td>Stroke Duration</td>
<td>1,8</td>
<td>26.972</td>
<td>.001</td>
<td>.771</td>
</tr>
<tr>
<td>ALL</td>
<td>Utterance Duration</td>
<td>1,8</td>
<td>47.923</td>
<td>&lt;.001</td>
<td>.857</td>
</tr>
</tbody>
</table>

Note. TF = tongue front, TM = tongue mid, J = jaw, LL = lower lip, UL = upper lip, ALL = all articulators.

Spatiotemporal Index Measures

The repeated measures ANOVA revealed significant differences in STI measure for the main ANOVA, DAF slow, and fast conditions. There was a main effect of rate for STI measure across the main ANOVA for tongue mid, tongue front, lower lip, and lip aperture. There was a main effect of rate for STI measure across the slow and typical conditions for the tongue mid, tongue front, jaw, and lower lip. There was a main effect of rate for STI measure across the fast and typical conditions for the lip aperture. STI measures decreased significantly for the upper lip only under the slow condition. For the delayed auditory feedback condition, STI measures did not change significantly for any articulators. The ANOVA did not reveal significant differences in lip aperture STI for neither the DAF nor the slow condition (See Tables 7, 8, 9 and 10).
Table 7

Means and Standard Deviations of the STI for the Typical, DAF, Slow, and Fast Conditions

<table>
<thead>
<tr>
<th>Articulator</th>
<th>TYP</th>
<th></th>
<th></th>
<th></th>
<th>DAF</th>
<th></th>
<th></th>
<th></th>
<th>MEH</th>
<th></th>
<th></th>
<th></th>
<th>MET</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>TM</td>
<td>23.43</td>
<td>6.78</td>
<td>25.18</td>
<td>5.71</td>
<td>32.69</td>
<td>8.54</td>
<td>20.04</td>
<td>7.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TF</td>
<td>24.21</td>
<td>6.32</td>
<td>25.59</td>
<td>6.88</td>
<td>33.78</td>
<td>7.10</td>
<td>19.76</td>
<td>6.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>23.33</td>
<td>5.12</td>
<td>27.94</td>
<td>5.75</td>
<td>34.10</td>
<td>8.39</td>
<td>26.33</td>
<td>9.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>24.20</td>
<td>6.07</td>
<td>28.48</td>
<td>6.16</td>
<td>33.94</td>
<td>8.01</td>
<td>22.24</td>
<td>7.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UL</td>
<td>29.79</td>
<td>6.48</td>
<td>32.12</td>
<td>4.80</td>
<td>36.53</td>
<td>7.53</td>
<td>28.80</td>
<td>6.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lip Ap</td>
<td>24.4</td>
<td>7.57</td>
<td>26.71</td>
<td>6.87</td>
<td>34.29</td>
<td>8.98</td>
<td>17.65</td>
<td>5.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Slow = magnitude estimation half typical speech rate, Fast = magnitude estimation twice typical speech rate, TM = tongue mid, TF = tongue front, J = jaw, LL = lower lip, UL = upper lip.

Table 8

ANOVA Main Effects of Rate Conditions on STI

<table>
<thead>
<tr>
<th>Articulator</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>3,27</td>
<td>8.88</td>
<td>&lt;.001</td>
<td>0.497</td>
</tr>
<tr>
<td>TF</td>
<td>2.457,22.112</td>
<td>11.611</td>
<td>&lt;.001</td>
<td>0.563</td>
</tr>
<tr>
<td>LL</td>
<td>3,27</td>
<td>6.216</td>
<td>0.002</td>
<td>0.409</td>
</tr>
<tr>
<td>Lip Ap</td>
<td>3,27</td>
<td>10.579</td>
<td>&lt;.001</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Note. TM = tongue mid, TF = tongue front, LL = lower lip, Lip Ap = lip aperture.

Table 9

Concurrent Contrasts for STI of Slow Versus Typical

<table>
<thead>
<tr>
<th>Articulator</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>1,9</td>
<td>25.134</td>
<td>0.001</td>
<td>0.736</td>
</tr>
<tr>
<td>TF</td>
<td>1,9</td>
<td>33.616</td>
<td>&lt;.001</td>
<td>0.789</td>
</tr>
<tr>
<td>J</td>
<td>1,9</td>
<td>13.926</td>
<td>0.005</td>
<td>0.607</td>
</tr>
<tr>
<td>LL</td>
<td>1,9</td>
<td>11.327</td>
<td>0.008</td>
<td>0.557</td>
</tr>
</tbody>
</table>

Note. TM = tongue mid, TF = tongue front, J = jaw, LL = lower lip.
Table 10

**Concurrent Contrasts for STI of Fast Versus Typical**

<table>
<thead>
<tr>
<th>Articulator</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lip Ap</td>
<td>1.9</td>
<td>21.223</td>
<td>0.001</td>
<td>0.702</td>
</tr>
</tbody>
</table>

*Note.* Lip Ap = lip aperture.

**Discussion**

The present study examined the effects of different speech rate cueing modalities on speech movement patterns. Several kinematic measures showed significant changes when speakers were cued using delayed auditory feedback or to increase or decrease their speaking rate.

**Speech Movement Patterns**

**Stroke Count**

There were significant changes in the stroke count measure in the slow condition for all articulators and in the fast condition for upper lip only compared to the typical speaking condition. Velocity patterns of the tongue were examined by Adams et al. (1993) in response to increased and decreased rates of speech. In their study, the tongue movement pattern for an increased speaking rate displayed one large velocity peak while a decreased speaking rate resulted in multiple, unequal velocity peaks (Adams et al., 1993). In the present study, the stroke count would be reflective of the number of velocity peaks in an utterance. Thus, the finding that stroke count increased at slower and decreased in faster speaking rates was consistent with Adams et al. (1993), even though they used different instrumentation and analysis methods from the current study.

The cause of the significant changes in stroke count with rate could be a difference in the programming of motor speech movements, resulting in several smaller individual strokes rather
than fewer, larger strokes for the same utterance. An increased rate involved combined articulatory movements that are simpler and fewer in number compared to typical rate.

**Onset, Peak, and Mean Speed**

Onset speed, or the speed of an articulator’s initial movement into a stroke, increased significantly for the lower lip in the fast condition, decreased for the tongue mid and tongue front in the slow condition, and decreased for the tongue mid in the DAF condition.

Peak speed, or the maximum speed an articulator’s movement during a stroke, increased significantly for the lower lip in the fast condition, decreased for tongue mid, tongue front, and upper lip in the slow condition and decreased for the tongue mid in the DAF condition.

Mean speed, or the average speed of an articulator’s movement during a stroke, increased significantly for the lower lip only in the fast speech condition, decreased for the tongue mid, tongue front, and upper lip in the slow speech and decreased for the tongue mid in the DAF condition.

These findings reflect systematic changes in articulator movement speed in response to slower or faster rate of speech. In other words, as articulators increase or decrease the overall speed of movements to produce more rapid or slow speech, the onset, peak, and mean speeds would also individually increase or decrease compared to typical rate of speech.

However, it should be noted that while there were changes in the stroke speeds for the tongue and lips, the onset, peak, and mean speed of the jaw movements were not significantly changed under any condition. These differences may be due to the relative mass and typical function of the jaw. Compared to the tongue, the jaw has more mass but less flexibility in its motion. Under the speaking conditions in the present study, it appears that the significant
changes in the speed of lip and tongue movements compensated for the lack of changes in the movement patterns of the jaw.

Changes in the stroke count were observed for multiple articulators, as previously noted, primarily increasing under slow conditions. Although the onset, peak, and mean speed for the movements of the jaw did not change significantly, the number of articulatory strokes increased and decreased to match the speech rate. Thus, there were some changes in how the jaw moved, but they differed in their nature from those observed for the other articulators.

**Stroke and Utterance Duration**

Stroke and utterance duration significantly decreased in the fast condition and increased in the slow condition. These findings are consistent with the expectation that articulation rate and movement duration correspond. This measure confirmed the ability of the speakers to adjust their speaking rate in comparison with their typical rate of speech.

Although stroke and utterance duration showed significant changes for the fast and slow conditions, there was no significant change in the DAF condition. In a study by Stuart et al. (2002), DAF effects on typical speakers produced two to three times more disfluencies and increased the duration of utterances more with a 200 ms delay than with 50 ms. The speakers in the current study spoke with a delay of 150 ms, which suggests that an increased delay might have resulted in more disfluencies and longer utterance durations.

While the reason for this is unclear, it could possibly be due to individual variability in response to DAF and its effects. While some speakers experienced significant disfluencies and slow speech, others appeared unaffected by DAF. Moreover, the speakers were provided sentences to read which may have assisted as a support. Stuart and Kalinowski (2015) found that although disfluencies were noted at a normal rate of speech using DAF, it did not significantly
decrease the rate of speech during the utterance. Future studies may consider applying speech rate adjustments while using DAF with both typical speakers and those with dysarthria.

**Hull Area**

Hull area displayed a significant increase for the tongue mid in the slow condition and a significant decrease in the fast condition. Previous work has shown that dysarthric speakers demonstrated an increase in vowel space area as speaking rates decreased (Turner et al., 1995). Although vowel space differs from hull area, the measurements are similar as both represent articulatory space. The results from Turner et al. (1995) suggest that slower speaking rates increase the articulatory area by allowing the articulators ample time to move and achieve the correct placement. As articulation accuracy increases, intelligibility increases. Thus, a slower speaking rate likely increases general intelligibility. The decrease in hull area in the fast condition is indicative of smaller movements in order to achieve a faster rate. Therefore, articulators have less time to reach their targets which would potentially result in a reduction in intelligibility. In contrast, this study found no significant changes in hull area for any articulators in the DAF condition. As stroke and utterance duration did not change in the DAF condition, likewise, hull area did not change.

**Spatiotemporal Index**

Based on previous findings on STI in speakers with dysarthria, it was hypothesized that articulatory patterns in slow and DAF conditions would be inconsistent, resulting in an increase in STI. In the current study, there was a main effect of rate for STI measures across the typical and slow condition for the tongue mid, tongue front, jaw, and lower lip. However, STI did not reveal significant changes in the DAF or fast conditions. Smith et al. (1995) discovered that when speakers were asked to decrease their rate, articulatory patterns became less consistent.
Therefore, the hypothesis that STI would increase in the slow condition was supported and the results are in agreement with prior research and expected outcomes. The hypothesis that STI would increase in the DAF condition was not supported. This could be due to the fact that utterance duration did not change in this condition. The impact of speech rate modifications have potential clinical significance because modifications in rate are regularly used to boost intelligibility in dysarthric individuals (Yorkston et al., 2007).

**Cueing Modality**

Rate reduction, as elicited in this study by encouraging the participant to speak at half their normal rate and with DAF, could be expected to improve articulatory performance. This study found that during the fast condition, participants displayed significantly less variability, whereas the slow condition led to greater variability compared to habitual speech.

It was hypothesized that both the slow and DAF conditions would produce significant changes compared to the habitual rate. A common question pertaining to rate control methods is why some rate control methods increase intelligibility in certain individuals but not in others. While intelligibility measures were not part of the present research, previous studies have indicated that lower STIs are associated with increased intelligibility (Tjaden et al., 2014). The lack of significant changes in STI measures in the fast versus typical and DAF versus typical conditions could be explained as reliably intelligible speech with both approaches. It is unclear as to why significant changes were not found under the DAF condition except that, as stated previously, not enough is known about the effects of DAF and how it impacts the rate and intelligibility of a typical or dysarthric speaker. Furthermore, this would also suggest that voluntary rate reduction, or speaking at a slow rate, might not always improve intelligibility. A study by Van Nuffelen et al. (2009) found that slow rate significantly decreased intelligibility in
22 out of 27 participants with dysarthria. Although the current study’s participants were typical speakers, this appears to correspond with the research by Van Nuffelen et al. (2009).

Comparably, Tjaden et al. (2014) did not observe enhanced intelligibility during a reading passage spoken at a slow rate by individuals with multiple sclerosis or Parkinson’s disease. It is possible that prosodic cues, which are often limited at a slower rate, could perhaps have a negative effect on intelligibility. As a result, it appears possible that such prosodic compromises could have been a hindrance to increased intelligibility in the slow condition. Future research examining rate control are needed to investigate if prosodic changes during slow speech can negatively impact intelligibility.

**Limitations and Directions for Future Research**

The current study provides insight into the connection between cueing and speech movement patterns under two rate control methods. However, the inferences one can draw are subject to certain limitations. This study involved a sample size of 10 subjects ranging in age range of early 20s to mid 30s. Future studies could expand the sample size and include a wider age range, including older adults in advanced age who are more likely to experience neurological illness. Since dysarthria often occurs with such conditions, it may be beneficial to gain a clearer understanding of the typical speech movement patterns and function in individuals of a similar age to those experiencing dysarthria.

Additionally, another limitation relates to the method used for obtaining the speech data. The participants repeated the target sentences multiple times in each of the speaking conditions with 3mm sensor coils glued to their articulators. This study examined the articulatory kinematics of one of the sentences produced multiple times. While this method was necessary to collect data using the electromagnetic articulography and directly compare these data within and
across participants, it is not fully generalizable to typical speaking patterns. When the sensors were attached, the participants spoke continuously for 10 minutes to provide time for adaptation before these data were collected; however, some participants might have needed more than 10 minutes to fully adapt to the sensors. The sensors may reduce the tactile feedback used in speaking and the lack of adaptation may cause acoustic and perceptual changes compared to typical speech.

**Conclusion**

As this study was designed to gather information about the typical speech movement patterns, the participants included only neurotypical individuals with no history of neurological, speech or language impairment. Despite these limitations, the findings provide insight into the speech mechanism and are a basis for future studies to include dysarthric individuals, which may provide insight into the effect of dysarthria and cueing modalities on speech movement patterns.
References


APPENDIX A

Annotated Bibliography

https://doi.org/10.1044/jshr.3601.41

**Objective:** The study utilized an x-ray microbeam system to analyze the influences of speaking rate on the velocity profiles of movements (lower lip and tongue tip) during the production of stop consonants.

**Method:** The participants included five native English speakers (one female and four males, 19-35 years old). Each subject repeated the phrase, “tap a tad above” 10 times at five different speaking rates, from very fast to very slow, for a total of 50 utterances. Participants were instructed to use a casual, conversational style of speech. Speaking rates were achieved using a magnitude production task wherein participants were told a value of 10 represented their habitual conversational speaking rate. They were subsequently given numbers greater and less than 10 and asked to increase or decrease speaking rate. Throughout the speaking tasks, an x-ray microbeam system was utilized to track and record the movements of small radio dense markers attached to the tongue tip and lower lip.

**Results:** Results suggested that variations in speaking rate were correlated with variations in the speech movement velocity-time function. At the fast-speaking rates, the velocity profile shifted from a proportioned, single-peaked function to an irregular and multi-peaked function at the slow-speaking rates. This variation in velocity profile shape
is possibly due to alterations in speaking rate, which are related to changes in motor control strategies.

Conclusions: The control strategy for speech gestures spoken at fast speaking rates seems to consist of singular actions that are most likely preprogrammed, whereas gestures spoken at slow speaking rates involve multiple smaller movements that are most likely affected by feedback processes.

Relevance to the current study: This study analyzes articulatory movements affected by self-directed speech rates, particularly the tongue tip and lower lip. The current study examines similar articulatory patterns at different speech rates including up to 5 articulatory sensor placements.


Objective: The purpose of this article was to describe and examine various rate control interventions for speakers with dysarthria.

Summary: The rate control methods explored in this article were pacing boards, alphabet boards, visual and auditory feedback, cueing and pacing strategies, and delayed auditory feedback. Pacing boards are used to segment speech, such as syllables, using allocated segments either tapped or read by the speaker with the intent to slow their rate of speech and in the process, intelligibility improves. During rate control intervention, a pacing board was introduced initially before progress to other methods due to its simplicity of use. Alphabet boards are applied to speech rate control similarly to a pacing board, pointing to the first letter of each word as they speak, decreasing their speech as they subsequently point. Research denotes the effectiveness of alphabet boards in
reducing speech rate and increasing intelligibility. Visual and auditory feedback involves any continuous visual or acoustic feedback about the individual’s speech, permitting the individual to alter the behavior or speech patterns to achieve an objective measure. Although research indicates improvements in intelligibility during visual and auditory feedback, maintenance of improved speech behaviors is not apparent but rather regression of learned behaviors. An external rhythm, such as metronome, or auditory production, such as modeling by a clinician, are the most common cueing and pacing strategies. This type of cueing ensues more natural-sounding and less robotic speech. Cueing and pacing strategies are likely to sustain improved speech behaviors long-term. Speakers using delayed auditory feedback produce naturalness of speech, but most speakers do not maintain the speech behaviors without constant delayed feedback.

Relevance to Current Study: The information in this study is relevant to the current study because it presents common rate control methods, its effectiveness, and what still needs to be identified. The current study seeks to compare the effect of two rate reduction approaches on speech movement patterns.


https://doi.org/10.1016/0093-934x(89)90080-1

Objective: The study analyzed whether speaking rate impacts articulation characterized by slow and reduced movements (articularatory hypokinesia) often observed in Parkinson’s disease.

Method: The participants included 12 male individuals with Parkinson’s disease. Each participant was screened to classify rigidity and severity of disease and to rule out
dementia and other similar disorders. Perceptual judgements of a 2-minute speech sample were analyzed from each participant by certified speech language pathologists. The participants were instructed to speak in comfortable conversational speech about their experiences with parkinsonism, their understanding of the disease, their responses to medication, and explanation of the procedures used to evaluate speech motor control. The participants also repeated 10 sentences beginning with 6 syllables and increasing to 10 syllables. They contained mostly bilabial and labiodental phonemes. The speech language pathologist first determined if the speaker was dysarthric and if so, the sample was rated on severity in prosody, speaking rate, articulatory precision, and phonation using a 5-point interval scale. An overall severity rating was also assigned to each speaking sample. The speech sample consisted of repeating a monosyllable /ba/ (i.e., /babababa/) spoken at four separate speaking rates: comfortable, faster, still faster, and as fast as possible. Speakers were asked to repeat the monosyllable until told to stop. All subjects wore a 9-mm intraincisal bite block to increase lower lip movement and to reduce jaw movements. A kinematic analysis consisting of labial displacement amplitude, peak instantaneous velocity, and movement time were evaluated for each syllable for both speaking rate conditions. Correlational analyses were conducted to evaluate the relationship between labial movement and each of the following clinical measures: age, year post onset, disease severity, dysarthria severity, perceptual ratings of speaking rate, and passive labial rigidity.

Results: The results indicated that labial movements were typical at the slowest speaking rate. As speaking rates increased to the speed of conversational speech, labial movements became hypokinetic.
Conclusion: The outcomes of the study suggest that speaking rate is an essential control variable and influences articulatory hypokinesia in Parkinson's disease. Additionally, these outcomes offer quantitative evidence that articulatory hypokinesia has a crucial role in the perception of dysarthria in Parkinson’s disease.

Relevance to the current study: The current study examines similar speaking rate effects on articulatory patterns (including labial patterns analyzed in this study) using kinematic analysis. This study provides quantitative results on the relationship between speaking rate, articulation, and perception similar to the current study.


Objective: The objective of this study was to examine the range of individual variation in response to delayed auditory feedback (DAF) to identify factors that may influence an individual’s reliance on auditory feedback.

Method: A group of 62 fluent speakers (29 men and 33 women, 18-30 years old) participated in this study. Spontaneous speech samples were obtained from participants during casual conversation on selected topics such as movies, hobbies, and vacation plans. Each participant performed under amplified nondelayed auditory feedback (NAF) and 250-ms delayed auditory feedback (DAF) conditions. Using the SALT program, the speech samples were transcribed identifying nine types of disfluencies classified into two general categories: stutter-like disfluencies (SLDs) and other disfluencies (OD). Speech articulatory errors (SEs) were also coded. Mean articulation rate (AR) was calculated for
each participant by dividing the number of perceptually fluent syllables by the duration of fluent speech in seconds for each utterance. Based on the number of SLDs they produced, participants were structured into three subgroups post-experiment: low responder, intermediate responder, and high responder (e.g., high responders showed elevated values in both SLDs and SEs).

Results: For all participants, the rate of SLDs in spontaneous speech was significantly higher under the DAF condition than in the NAF condition, with a large effect size. There was not a significant difference between male and female participants. Female participants produced significantly fewer ODs in both conditions than male participants, but there was not a significant difference between feedback conditions. Articulation rate was significantly slower for all participants under the DAF condition than the NAF condition, and male participants showed significantly faster articulation rates than female participants under the DAF condition. There were significantly more SEs produced by all participants under the DAF condition. Each dependent variable (i.e., articulation rate and number of ODs, SLDs and SEs) showed a higher variability between individual participants under the DAF condition as compared to the NAF condition. Participants identified as low responders had the lowest SLD and SE counts under DAF. Intermediate responders had an intermediate range of SLDs, but the highest articulation rates and SE counts. High responders had the highest SLD counts, and broad range of SEs and the slowest articulation rates.

Conclusions: DAF may lead to a significant increase in stutter-like disfluencies as evidenced by a notable reduction in articulation rates in fluent speakers. There are substantial inconsistencies between individuals in their predisposition to DAF and their
capacity to speak fluently under these conditions, which may be associated with a range in speech motor skills.

Relevance to the current study: The current study is aimed at understanding how DAF affects articulatory patterns. This report illustrates several factors that influence an individual’s dependence on auditory feedback.


**Objective:** The objective of this study was to establish the most effective method to increase both intelligibility and acceptability of disordered speech via modifications to speaking rates in individuals with dysarthria by increasing or decreasing their rate by 30%.

**Method:** Four individuals with moderate, acquired dysarthria and two speakers with non-neurological conditions participated in this study. Using the Assessment of Intelligibility of Dysarthric Speech (AIDS), each participant read sentences at a habitual rate while being audio recorded. Using COOL EDIT software, two additional audio files were created: one at a rate 30% faster and one at 30% slower than the original habitual rate. A group of 30 undergraduate and graduate students were distributed into three groups of ten, functioning as judges, rating randomized audio files on a scale of 1 to 9 for half the audio samples. For intelligibility purposes, they were given the second half of audio samples and instructed to type what they heard onto a computer screen.

**Results:** The two control participants’ mean acceptability scores were 7 or higher (1 to 9 scale) for each condition (slowed, increased, habitual). Regardless of speaking
conditions, mean acceptability rates fluctuated significantly among speakers with dysarthria. Speakers 1 and 2 scored significantly higher on the fast audio samples compared to their habitual sample. Speakers 3 and 4 scores displayed little significant difference between the fast and habitual samples. Significant variance was seen in mean intelligibility scores for all speakers with dysarthria. Speaker 1 scored the highest in rating while speaker 4 scored the lowest. For all three rate conditions, no significant differences were noted in intelligibility ratings among speakers.

Conclusion: In each of the four speakers, varying speech rate did not alter the intelligibility ratings. The speakers with average intelligibility were noted to increase acceptability of speech as rate increased. However, for the speakers with reduced intelligibility, there was no correlation between increased rate and improved intelligibility. The adaptation of rate appeared to decrease intelligibility as it may be that speakers with diminished speech capabilities function at a lower level when taken further from their habitual rate for both acceptability and intelligibility.

Relevance to current study: The information in this study is relevant to the current study because the results suggest that speakers with mild impairments may experience a greater increase in naturalness of speech when an increase in speaking rate is produced. Varied speaking rate conditions are introduced in the current study to explore the effects of rate control on articulatory patterns.

Objective: The purpose of this study was to compare traditional rate reduction methods with delayed auditory feedback (DAF) and evaluate their ability to decrease speech rate and increase intelligibility in speakers with dysarthria secondary to Parkinson’s Disease (PD).

Method: The participants included 11 speakers with dysarthria secondary to PD, and who used delayed auditory feedback (DAF). The speakers were given two therapy intervention approaches: traditional therapy (i.e., increasing pausing, reducing speech rate, stretching out articulation) and DAF. Intervention was given once weekly for 50-60 minutes for 6 weeks. A reading task and monologue task were used as data and rated based on two speech parameters: speech rate and intelligibility. A reading task was given from the “Cherry Tree” passage and read aloud after participants had become familiar with the passage. The monologue was based on a memory beginning with “Tell me about leisure/family/school/childhood.” Participants were asked a different stimulus question at each evaluation point and for each feedback condition. The reading task was performed with no feedback and with DAF. Speech rate was measured as the number of syllables produced per second including pauses. For the reading passage direct magnitude estimation was used to counteract familiarity with the passage. For the monologue, listeners used a 9-point Likert scale. Intelligibility was measured by comparing speakers with each other; each speaker acted as their own standard.

Results: As a group, there was no significant change in response to either treatment type. However, individual speakers showed improvements in speech performance because of each therapy technique. DAF induced significantly slower speech at any given time. These rate reductions did not automatically translate into
intelligibility improvements. The benefit of treatment lasted at least 6 months for most participants. Two speakers displayed dramatic improvements from DAF. In these two individuals, intelligibility was significantly increased and sustained for 24 months after initial treatment. The drawback to the treatment was the requirement of a portable body-worn DAF device, because the speakers only saw benefits when DAF was in use.

**Conclusion:** Individuals with dysarthria in this study were shown to have decreased rate of speech but intelligibility was not shown to have increased as a result of DAF. Results thus far have been inconclusive and additional research is needed to determine if DAF provides a consistent and effective treatment approach for improvements in intelligibility and rate reduction.

**Relevance to the current study:** This study sought to determine if DAF was an effective treatment method to decrease speech rate and increase intelligibility in dysarthric individuals. The current study seeks to determine how DAF influences articulatory patterns and rate of speech.


**Objective:** This study analyzed the time sequence of speech adaptation, using perceptual and acoustic measures, after the attachment of electromagnetic sensor coils to the tongue, lips, and jaw.

**Method:** The study had two parts: recording of audio data and an analysis of perceptual and acoustic measures. Participants included 20 native English speakers (10 women and 10 men, 20-32 years old). Participants read aloud stimulus sentences before
the attachment of the sensors, immediately after attachment, and again at delayed intervals of 5, 10, 15, and 20 minutes. To assist in adaptation, participants read aloud continuously. Using a visual analog scale, 150 stimuli sentence recordings were perceptually evaluated and labeled as “precise” and “imprecise” by 20 native English listeners. Using Praat, an acoustic analysis was performed by segmenting and measuring the duration of the fricatives /s/ and /ʃ/, due to the lingual placement of the sensor and its potential interference with fricative production. Additionally, whole sentences were acoustically analyzed using Praat in the same manner.

Results: Following sensor attachment, a decrease in speech precision was observed in perceptual ratings. After 10 minutes, little perceptual change was detected in participants potentially due to adaptation of the sensors. However, acoustic measures indicated no evidence of adaptation over time among fricatives following sensor attachment. The spectral center of gravity for /s/ decreased while the spectral standard deviation for /ʃ/ increased after sensor attachment.

Conclusions: The results of the study indicate that speakers adapt to Northern Digital Instruments Wave electromagnetic sensors after 10 minutes. This suggests a necessary 10-minute adaptation period as the optimal timing before experimental data are collected.

Relevance to the current study: This study provides insight on the suggested ideal time to allow for adaption of a speaker to sensors before collecting data. This applies to the current study as it uses equivalent sensors to collect data and requires adaptation to collect accurate kinematic recordings.

**Objective:** The purpose of this study was to examine the effects of speech rate and sound pressure level adjustments during sentence production across three speech subsystems (respiration, phonation and articulation).

**Method:** An experimental group of 10 neurotypical participants (5 male and 5 female, ages 23-34) were included in this study. Under nine conditions, the participants were given directions to repeat the sentence, “I sell a sapapple again.” These conditions included habitual speaking rate, twice and four times as fast as habitual, half and a quarter of habitual, twice and four times as loud as habitual speaking volume, and half and a quarter as loud as habitual. Each participant was instructed to modify their speech to match each condition in order. Participant measurements were taken for sound pressure level, articulatory movements of the upper and lower lips, utterance duration, and changes of the ribcage and abdomen under each condition.

**Results:** Overall, as sound pressure level (SPL) increased, the displacement and velocity peaks of the upper and lower lips increased as did fundamental frequency. At initiation and termination of speech, lung volumes notably increased in comparison to habitual SPL. A reduction in lip movement and consistency resulted as rate of speech increased. Inconsistencies appeared across lower and upper lip velocity peaks among individuals as rate was altered. An increase in fundamental frequency was observed as
rate of speech increased. Phonation, respiration, articulation showed remarkably significant effects resulting from variations in SPL rather than alterations in speech rate.

**Conclusion:** Speech loudness and rate alterations led to changed articulatory movement patterns in each of the participants. Speech subsystems may be influenced more substantially by increased speech loudness levels compared to an increased rate of speech. It is possible that consistent changes in phonation and respiration can be attributed to adjustments in SPL compared to rate of speech. This can be applied to treatment of individuals with dysarthria and to further research in this area.

**Relevance to current study:** The kinematic measures gathered in this study aimed at better understanding how articulation is influenced by rate and SPL in typical speakers. The movements of the articulators, such as the upper and lower lip, that were measured in this study will likewise be measured in the current study. The current study will similarly examine articulatory patterns and its movements in response to rate control.


**Objective:** The intention of this book is to provide current techniques, approaches, and case studies to educate graduate students, clinicians, and researchers in the field of speech-language pathology. It focuses on acquired motor speech disorders in adults, integrating what is known about motor speech disorders and with current clinical practice in the field of speech-language pathology.

**Summary:** This book is organized into three parts, with the first focusing on the neurological foundations of speech and its disorders, the second focusing on nervous system disorders and their diagnoses, and the third focusing on the principles and
management of these motor speech disorders. It offers basic and in-depth information about a variety of motor speech disorders including all types of dysarthria, apraxia of speech, acquired psychogenic and related nonorganic speech disorders, neurogenic mutism, and other neurogenic speech disorders. It also addresses differential diagnosis and current evidenced-based treatment approaches for each motor speech disorder. This book provides the reader with a comprehensive approach and understanding of motor speech disorders, their etiologies, and characteristics of motor speech disorders as well as research-based evaluation, diagnosis, and treatment of such disorders.

Relevance to current study: The current study examines the effect of rate control treatments on articulatory patterns. As such, this book is pertinent to the current study because it offers evidence about current rate control treatments and their efficacy in patients with dysarthria.


Objective: The purpose of this study was to analyze the effect of rate reduction on speech and pause characteristics in hypokinetic dysarthria. It aimed to examine the correlation between speech and pause characteristics as well as intelligibility after rate of speech is reduced.

Method: An experimental group of six speakers with Parkinson’s disease (5 males and 1 female, 56-77 years old) participated in the study. A control group of six non-neurologically impaired individuals were matched by age (+/- 3 years) and gender with the experimental group. Participants engaged in recording tasks of habitual and paced
reading. The habitual reading condition was displayed via a computer screen presenting the stimulus passage and first being read aloud to the subject before the production. Instructions were not given concerning rate. In the paced reading condition, a computerized pacing software controlled the paced reading rate targeted at 60% of the speaker’s habitual reading rate. The following measures were used to examine the samples including speech duration, pause duration, interpause phrase length, pausal location, intra-examiner reliability, and inter-examiner reliability. Speech duration was analyzed in milliseconds and as a percentage of the cumulative reading duration. Pause duration consisted of a silent period on the acoustic waveform greater than 150 msec in duration. Interpause phrase length was calculated by manually tallying the number of words between pauses. Pausal location was marked and separated into two categories: syntactically appropriate and syntactically inappropriate. Intra-examiner reliability consisted of a random selection of 33% of the participants to calculate the difference in duration between the first and second measures. Inter-examiner reliability consisted of a random selection of 33% of participants (different from intra-examiner) to calculate the total difference in pause duration between the original and second set of measures.

Results: The results of the habitual reading rates showed that the group with Parkinson’s disease (PD) displayed a mean reading rate of 268 syllables per minute while the control group had a mean reading rate of 216 syllables per minute. The paced reading rate used the PACER program to slow the rate of speech in the participants and indicated that 4/6 speakers with PD were within +/- 5% of the paced reading rate during the paced conditions while the remaining 2 speakers were within 7% of the paced rate. Pause duration was increased more than speech during the pacing condition in both groups with
a 156% increase for PD and 209% increase for the control. At habitual reading rates participants with PD had nearly the same average pause duration as the control group; however, pausing occurred more frequently within a phrase or clause. Neither group had statistically significant results in the pause duration and phrase length.

**Conclusions:** This study confirms that speakers with PD have a faster rate of speech than control speakers. These results verify the PACER technique’s efficacy in regulating reading rate and are congruent with previously published literature. When speech rate is altered, pause duration more often reflects the change in overall rate than does the speaking duration.

**Relevance to current study:** The information in this study is relevant to the current study as it confirms faster rate of speech in individuals with hypokinetic dysarthria and uses similar reduction rate control methods.


**Objective:** The purpose of this study was to measure variations in speech intelligibility in individuals with Parkinson’s disease (PD) across a wide range of speech rate modifications in sentences and monologues.

**Method:** Experimental groups of four participants (69 total) were included in this study: younger and older controls, people with PD undergoing standard pharmaceutical treatment, and people with PD with deep brain stimulation (DBS) and without DBS. Listeners consisted of six female graduate students from Western University in the speech-language pathology program. They rated the intelligibility of read sentences and
monologues, spoken by participants at seven self-selected speech rates: habitual rate, three slower rates, and three faster rates. For each speaking task, the participant was asked to speak at a rate that felt (2x/3x/4x) faster/slower than their normal speaking rate. Each rate task was self-paced by the participant’s perception of decreasing or increasing rate rather than objective rates of speech such as words per minute. Intelligibility was modeled as a function of group, speech rate condition, and speech task.

**Results:** Slower rate conditions were not associated with fluctuations in speech intelligibility when compared to habitual speech rate. Faster-than-habitual conditions were associated with decreased intelligibility. Speakers with PD and DBS saw greater benefits in intelligibility at self-directed slower speech rates than at faster rates. Increasing the rate of speech had a negative effect on speakers with PD and DBS resulting in overall decreased intelligibility. Differences in intelligibility were seen to decrease or increase at greater increments in monologues compared to sentences.

**Conclusions:** Speakers with Parkinson’s disease with and without DBS had changes in speech intelligibility when using slower and faster speech rate modifications. At all three faster rate conditions, significant declines in intelligibility occurred with the group with PD without DBS compared to the group with PD with DBS. The outcomes support earlier findings that slower-than-habitual speech is usually associated with increases in intelligibility for many speakers with PD; however, substantial improvements were observed in speakers with PD and DBS. Although faster self-selected speech rates were associated with decreases in intelligibility, a pattern for increased intelligibility was noted from some speakers.
Relevance to the current study: This study aimed to quantify changes in speech intelligibility resulting from self-selected rate modification in individuals with Parkinson’s disease with and without DBS. The current study also seeks to examine similar self-selected rate modification effects on articulatory movement patterns.


Objective: This study investigated the effects of delayed auditory feedback (DAF) on speech rate and articulatory response effects on intelligibility in speakers with Parkinson’s disease (PD).

Methods: The participants included highly intelligible speakers with PD (HPD), low intelligible speakers with PD (LPD), and highly intelligible unimpaired control speakers (CON). The speakers read sentences under immediate auditory feedback (IAF) and two conditions of DAF (50 and 150 milliseconds delay). Intelligibility and speech rate measures were analyzed for all speakers during conditions of IAF and DAF.

Results: The study found that reduced speech rates during DAF were correlated with increases in speech intelligibility for LPD speakers, decreased intelligibility in HPD speakers, and intelligibility was unaffected in CON speakers. LPD speakers reduced their speech rates more than HPD and CON speakers from IAF to DAF conditions. These variations were not statistically significant.

Conclusion: Outcomes from this and previous studies suggest that a clinician should consider the severity of speech impairment when deciding on the therapy approach utilized for rate reduction.
Relevance to the current study: This study focuses on the effects of DAF on speech rate and articulation patterns in terms of intelligibility and appropriateness of treatment. The current study aims to examine similar effects of DAF on neurotypical individuals to gather data to improve the use of DAF as a speech rate technique for speakers with dysarthria.


**Objective:** The purpose of this study was to develop an index of spatiotemporal stability by describing the stability and patterning of speech movements.

**Method:** A group of seven neurotypical adults participated in the study. Each participant was instructed to repeat the phrase twenty times, “Buy Bobby a puppy” in sets of ten, in fast rate and slow rate conditions. Participants were instructed to speak at twice their normal rate during the fast rate condition and half their normal rate during the slow rate condition. An acoustic signal was employed to estimate phrase duration for participant utterances on a storage oscilloscope. A cantilever was led through a small bead attached to the vermillion border of the participant’s lower lip at midline. This procedure was used to record the displacement of the lower lip during speech. Each rate condition consisted of fifteen short files of the filtered displacement signal. Each file consisted of an interval beginning at the peak velocity of the initial opening movement of the /b/ in the word “buy” to the peak velocity of the final opening movement of the first/p/ in “puppy”. An overall spatiotemporal index (STI) was created from the analysis
of the 15 files. The average number from the analysis revealed the overall spatiotemporal stability of a repeated utterance.

**Results:** There was a significant correlation of peak velocities between general movement duration and relative time of occurrence. The middle three opening movements in the phrase, “Buy Bobby a puppy” displayed total movement time at peak velocities occurring at 25%, 49%, and 76% for the fast condition, 29%, 51%, and 79% for the habitual condition, and 33%, 57%, and 84% for the slow condition. When compared to the normal condition, there was more variability in STI values for the slow and fast conditions with a substantial increase in STI values as participants progressed from a normal to a slowed rate.

**Conclusion:** It is probable that at slowed rates articulatory movements become less consistent. For the stability of speech movements, the computation of the STI provides a useful index.

**Relevance to current study:** This study has shown that the Spatiotemporal Index (STI) measure of the instability of speech movements over time tends to increase at slowed rates, implying less consistent articulatory movements at decreased speech rates. The current study seeks to examine similar influences of speech rate on articulatory movements.


**Objective:** The effects of perturbations in Delayed Auditory Feedback (DAF) and speech rate were examined between men and women.
**Methods:** The participants included 32 fluent adults (16 male, 16 female) with no prior exposure to DAF. Each spoke at a normal and fast rate of speech using DAF intervals (0, 25, 50, 100, and 200 msec). The participants read 10 passages with a similar topic and lexical difficulty, containing 300 syllables. For each condition, the number of disfluencies (per 300 syllables) and the syllable rate were calculated. The syllable rate was determined by dividing the number of syllables in the sample by the sample duration. An ANOVA analysis was performed to determine the effect of speech rate, DAF, and sex on syllable rate.

**Results:** When participants were asked to speak at a fast rate, the syllable rate substantially increased. As DAF delays increased, the syllable rate decreased. Under the conditions of 200 msec DAF and fast speech rate, the male participants speech rate was substantially faster. As DAF delays increased, disfluencies also increased. Under normal rate conditions, disfluencies occurred at 100 and 200 msec while substantially more disfluencies occurred at delays of 25 and 50 msec. at the fast rate condition. Differences between male and female in the number of disfluencies were not apparent.

**Conclusion:** The results of this study establish that gender differences in susceptibility to perturbations in DAF and speech rate suggesting the effects of DAF may be different between genders. When the participant’s voices were played back to them and altered in frequency, they responded by changing their F0 production in the direction opposite to the shifted auditory feedback. DAF in both genders of typical speakers promote disfluencies.
Relevance to current study: The current study seeks to determine the effects of DAF on typical speakers, as in this study, and expand the data to apply to DAF and its influence on speakers with dysarthria as a therapy approach.


**Objective:** This study explored the effect of short and long auditory feedback delays among normal speakers at two different speech rates.

**Method:** The participants included seventeen neurotypical adult males. They spoke under delayed auditory feedback (DAF) at 0, 25, 50, and 200 ms at normal and fast rates of speech. Participants read passages of 300 syllables consisting of related topics and syntactic difficulty. Passages were read at both speech rates (normal and fast) within each DAF condition with normal vocal intensity. While maintaining intelligibility, participants were instructed to read as fast as possible under the fast rate condition. DAF conditions were randomized, and speech rates were counterbalanced across all participants.

**Results:** Results displayed two to three times more disfluencies were exhibited at 200 ms (p=0.05) compared to 0, 25, and 50 ms delays. Additionally, there were considerably more disfluencies noted at the fast rate of speech (p=0.028).

**Conclusions:** DAF prompted considerably more disfluencies only at the longest delay of 200 ms. Neurotypical speakers were proficient at generating fluent or close to fluent speech with short auditory feedback delays (50 ms or less). More disfluencies were
marked at a fast rate of speech due to a greater motor load. Consistent with previous research, decreased speech rate was demonstrated at delays of 25 ms or more.

Relevance to the current study: This study aims to examine the effects of DAF in normally speaking adults presented at 200, 50, 25, and 0 ms stimuli. The current study also seeks to examine similar populations and stimuli in DAF but at a 150 ms delay.


Objective: The intent of the article was to illustrate a process of dividing movement signals into a sequence of separate movement “strokes.” This process was used to segment speech-related movements of the tongue blade, tongue dorsum, lower lip, and jaw in young, healthy individuals. Various physical events such as articulatory movements and muscle contractions co-occur, making kinematic analysis complex and difficult to segment individual articulator movements into separate and independent occurrences. During production of speech, articulators produce continuous and rapid movements, seldom resulting in a static position. Previous researchers have identified speech movement units as an excursion along a single movement dimension followed by an evaluation of characteristics of units for amplitude, velocity, or duration. Although this process was advantageous, some events are easier to identify from kinematic waveforms than others. Furthermore, a single movement dimension does not allow time and axis orientation to be independent factors. Movements along more than one axis can be simultaneously occurring, with time changes depending on the axis in use. The authors propose an alternative means of measurement, using magnitude of rate of change of
position relative to time, or movement speed without reference to direction. Applying this measurement, a movement unit is defined as an interval between two consecutive speed minima containing a period of acceleration followed by a period of deceleration.

Method: The participants included 18 speakers from the University of Wisconsin X-ray Microbeam Speech Production Database (XRMB-SPD). Each speaker participated in an oral reading of a script using a self-selected speaking rate. Articulator movements were recorded during the speech tasks using gold pellets glued to the blade and dorsum of the tongue, the gumline between the mandibular incisors and first and second molars, and on the vermilion border of the lower lip. The data from each sensor recorded the speed of each articulator during speaking tasks, resulting in movement strokes (period of movement between two points of minimum speed, separated by a maximum speed).

Results: The study suggests that sounds, syllables, and words are formed from the combination of strokes from multiple articulators and not from isolated strokes, as they do not accurately reflect the acoustic characteristics. The results of the study further emphasized this notion as there were a variety of numbers of strokes per articulator. There were fewer movement strokes than nearby phonemes, and more strokes than there were syllables or words.

Conclusion: In speech kinematic analysis, movement strokes are beneficial and can be identified without reference to speech units (words or syllables) or peripheral body movements. This is advantageous as it allows comparisons of motor behaviors and speech tasks in both neurotypical and neurodiverse individuals. This approach can also be automated and computerized, permitting wide-ranging and efficient data analysis.
Relevance to the current study: The movement strokes approach defined in this study will be applied in the current study to measure speech samples and analyze speech movement patterns in relation to rate reduction conditions.


Objective: This study examined perceptual consequences of rate reduction, increased vocal intensity, and clear speech in speakers with multiple sclerosis (MS), Parkinson's disease (PD), and healthy individuals.

Method: The participants included 78 speakers. The control group consisted of 22 speakers (10 male and 22 female). The PD group consisted of 16 speakers (8 male and 8 female). MS speakers consisted of 30 speakers (10 male and 20 female). The participants were asked to read sentences under four conditions (habitual, clear, loud, and slow). Using a computerized visual analog scale, listeners evaluated the participants’ naturalness and overall severity in each of the conditions based on voice, resonance, articulation, and timing. Voice was analyzed for overall quality, breathiness, noise, and pitch. Resonance was analyzed for hypo- and hyper-nasal. Articulation and rhythm were analyzed for overall precision and timing. Listeners were instructed to focus on how understandable each sentence was instead of focusing on intelligibility.

Results: The conditions of loud and clear demonstrated an increase in intelligibility comparative to the habitual condition. In contrast, the slow conditions not only did not improve intelligibility, but increased speech severity compared with all other
conditions. Apart from the loud condition for the PD group, speech severity did not improve beyond habitual and was lessened in some occurrences compared to habitual. The relationship between clear and slow was weaker compared to intelligibility and speech severity which were strongly correlated.

**Conclusions:** Both clear and loud speech demonstrated increases in intelligibility and maintenance of speech severity for individuals with mild dysarthria determined within this study. Further research is needed to establish maintenance over time and in conversational speech tasks. In sum, loud and clear speech seem to have comparable beneficial results on intelligibility and are not detrimental to naturalness of speech and speech severity.

**Relevance to the current study:** This study discusses the perceptual effects of rate reduction, vocal intensity, and speech severity in individuals with mild dysarthria, related to intelligibility and naturalness of speech. The current study seeks to analyze the impact of rate control as it pertains to articulatory patterns.


**Objective:** This study examines the effects of speaking rate in individuals with amyotrophic lateral sclerosis (ALS) on vowel space area and speech intelligibility.

**Methods:** The participants included nine individuals with ALS and nine typical individuals without neurological abnormalities. Each of the nine participants with ALS were matched for age and gender with controls. The speakers read from a standard
paragraph called “The Farm Passage.” Speakers read at three speaking rates: habitual, fast, and slow. At each speaking rate, vowel segment durations and target formant frequencies were calculated from words comprising the vowels /i/, /æ/, /a/, and /u/. Variations in vowel space area were calculated within each speaking rate. This was completed by measuring the vowel quadrilateral area for each participant at each of the three speaking rates. Intelligibility evaluations were also assessed at each speaking rate and collected for the nine dysarthric speakers.

**Results:** Four of the nine speakers had increased intelligibility when using naturally reduced rates. The dysarthric speakers demonstrated reduced vowel space areas and fewer consistent changes in vowel space pertaining to speaking rate, in relation to the neurologically intact speakers. In correlation between vowel space area and speech intelligibility, vowel space was the predicting factor for 45% of the variance in speech intelligibility.

**Conclusions:** The results suggest that vowel space area is an important component of acoustic estimates of speech intelligibility.

**Relevance to current study:** The current study examines speaking rates effects on articulatory patterns using kinematic analysis. This study provides quantitative results on the relationship between speaking rate, vowel space, and intelligibility in dysarthric speakers.

**Objective:** The purpose of this study was to analyze the effect of rate control methods in speakers with dysarthria on speaking rate (SR), articulation rate (AR), and intelligibility. Rate reduction often leads to improved articulatory displacements, improving intelligibility through the production of acoustically distinct productions.

**Method:** An experimental group of 19 dysarthric patients (13 men and 6 women, 17-88 years old) participated in this study. Seven rate control methods (RCMs) were employed during tasks of voluntary rate control, hand tapping, alphabet board, pacing board and delayed auditory feedback with a delay of 50, 100 and 150 ms. Speakers with dysarthria read aloud 20 different simple sentence passages, selected at random for the duration of 2 minutes. Two-minute samples were recorded in a quiet environment, presenting randomized RCMs conditions for each. Speech samples were analyzed for intelligibility by 5 speech-language pathologists using a 100-mm visual analogue scale (VAS), eliminating perceptual judgments that may influence intelligibility. Calculations included statistical analyses using SPSS 14 and syllables per second using a 1-minute mid-sample segment. Repeated-measures ANOVA was applied to analyze AR and intelligibility. The Bonferroni correction was applied for the post hoc pairwise comparisons. Significance level was established at p < 0.05.

**Results:** Lower mean SRs and ARs (p < 0.05) were found in most method outcomes. Overall intelligibility was not improved by rate control in the dysarthric group. However, 5 individuals displayed a significant increase in intelligibility. This study suggests the effect of rate control is independent of typical speech rate and type of dysarthria in terms of intelligibility. Voluntary rate control, alphabet board, hand tapping and pacing board proved to be the most effective methods.
Conclusion: Except for AR for voluntary rate control, the findings determined that all RCMs produced slower ARs and SRs. Although intelligibility was not increased by rate control in dysarthric participants, a significant increase of more than 8% was recorded in 5 speakers. RCMs caused slower speech rates. While various dysarthric individuals may profit from one or more RCMs, rate control may decrease overall intelligibility.

Relevance to the current study: The effects of rate control methods on rate and intelligibility in dysarthric speakers is parallel to the current study’s purpose. This study employs rigid rate control strategies to manipulate rate in dysarthric individuals, leaving nondisruptive techniques to be further researched and evaluated.


Objective: The study examined the impact of variations of speaking rate both acoustically and perceptually in individuals with and without amyotrophic lateral sclerosis (ALS).

Method: The participants included 10 (five males, five females) dysarthric speakers with ALS and 19 (10 males, nine females) neurotypical speakers. The participants were given three separate prerecorded stimulus sentences presented through a loudspeaker. Each sentence was introduced six times at a habitual rate and six times at a fast rate. Following the model’s rate of habitual or fast, speakers repeated each sentence immediately. Acoustic measures were obtained from each sentence spoken including total utterance durations, segment durations, and vowel formant frequencies. Perceptual
measures were obtained from each sentence spoken including magnitude estimates of speech intelligibility and severity of speech involvement.

**Results:** Results suggested that speakers in both the neurotypical and ALS groups were proficient at increasing their speaking rate, but that the speakers with ALS were considerably slower than the neurotypical participants at both habitual and fast rates. The perceptual measures displayed no effect on intelligibility or severity for either group.

**Conclusions:** The increased rate of speech did not perceptually demonstrate a speech deficit among speakers with ALS. This disagrees with the idea that habitually slow speech rates are a form of compensation to reduce the difficulty of speech production in individuals with dysarthria.

**Relevance to the current study:** This study analyzes the general issue of slow rate in habitual speaking rates characteristic of most speakers with dysarthria and provides possible reasons for the slow rate. The relationship between speaking rate and speech intelligibility was not linear. The current study provides a more sensitive, segmental analysis to determine and evaluate speech rate effects on intelligibility.


**Objective:** The purpose of this study is to identify the types and strength of evidence supporting the effectiveness of interventions on speech production in speakers with dysarthria.

**Method:** A systematic search of electronic databases (PsycINFO, MEDLINE and CINAHL) and a manual search of applicable edited books generated 51 articles for the
effectiveness of loudness, rate, prosody, and general instructions. The strength of evidence for intervention studies were grouped into stages of research and rated based on the type of research, how well the participants were described and the consequences of the intervention.

**Results:** The strongest evidence regarding treatment effectiveness is in modification of loudness in individuals with Parkinson's disease who have hypokinetic dysarthria. Future research should focus on larger groups of speakers, candidacy issues for the approach and studying actual rather than simulated communication breakdowns. Additional research is needed in the areas of consistency of evidence and its reporting, outcomes, participant criteria, and motor learning principles applied to intervention. There is a need for more level I studies regarding hypokinetic dysarthria.

**Conclusions:** Phase I studies included experimental treatments, including loudness, rate or prosody manipulations. Phase II studies included treatment protocols with no control or treatment comparison in speakers with dysarthria in case reports and small groups. Phase III studies included treatment protocols tested with single subject or group designs with control groups or treatment comparisons. This review included PD and other etiologies; however, most data were from individuals with PD.

**Relevance to the current study:** This study examines numerous experimental treatments on speakers with dysarthria including rate and intelligibility which is the primary focus of the current study.

**Objective:** The purpose of this study was to document the effect of controlling speaking rate on several perceptual aspects of speech, specifically sentence and phoneme intelligibility and naturalness of speech.

**Method:** An experimental group consisting of eight speakers with dysarthria, ages 30-70 and a control group of four individuals with no neurological conditions were used. Each experimental subject was asked to complete three tasks to measure sentence intelligibility, phoneme intelligibility, and speech naturalness. For the sentence intelligibility task, the experimental group read aloud 11 randomly generated sentences from the Computerized Intelligibility of Dysarthric Speech which were then orthographically transcribed and analyzed for percentage of words accurately transcribed by judges. For the phoneme intelligibility task, the experimental group read 19 sentences in which words containing a total of 57 vowels and singleton consonants were embedded. Judges were asked to identify missing sounds in the speech samples and each sample was scored for percentage of consonants and vowels correctly identified. For the speech naturalness task both the experimental and control groups read a paragraph at habitual and slowed rates. The recorded speech samples were then judged using a 7-point scale to compare the naturalness of one subject across a number of speaking conditions. Each speech sample in all three tasks was recorded under nine experimental conditions: habitual, and under four different rate control strategies (i.e., Additive Metered, Additive Rhythmic, Cued Metered, and Cued Rhythmic) at 80% of habitual rate, and at 60% of habitual rate. For the Additive Metered (AM) strategy, a speech sample was displayed word by word via a switch pressed by the examiner on a computer monitor. For the Additive Rhythmic (AR) strategy, a speech sample was displayed word by word using a
timing pattern simulating natural speech rather than equal durations for each word. For the Cued Metered (CM) strategy, the entire speech sample was presented on screen and individual words were underlined one by one at an equal duration. For the Cued Rhythmic (CR) strategy, the entire speech sample was presented as in CM, but words were underlined one by one following the timing of a natural speech pattern.

Results: For both groups, sentence intelligibility increased as speaking rate decreased. In addition, the greatest increases in speech intelligibility occurred under the Cued Metered (CM) and Additive Metered (AM) conditions. However, phoneme intelligibility did not increase for all subjects as speaking rate decreased. In fact, for some subjects, phoneme intelligibility decreased, and for those whose phoneme intelligibility increased with slowed rate, there was not a consistent increase across subjects. Speech naturalness scores decreased the most for the control group but did not change significantly for the experimental group.

Conclusion: Reduction of speaking rate can result in consistent increase in sentence intelligibility, particularly when metered pacing strategies are used. While the reduction of speech rate results in a decrease in speech naturalness, the effect on dysarthric speech is not significant, presumably because dysarthric speech is already unnatural.

Relevance to the current study: This study focuses exclusively on the perceptual impact of rate control on intelligibility while my study will focus on quantitative rate control across various similar rate strategies.
APPENDIX B

Consent Document Approved by the Institutional Review Board

Consent to be a Research Subject

Title of the Research Study: Kinematic and acoustic effects of different speech rate control techniques
Principal Investigator: Christopher Dromey, PhD
IRB ID#: IRB2020-413

Introduction
This research study is being conducted by Professor Christopher Dromey, assisted by Noelle Lewis, both from the Department of Communication Disorders at Brigham Young University, to determine how speaking at different rates affects how the tongue, lips, and jaw move. You were invited to participate because you are a native speaker of American English and have no history of speech, language, or hearing disorders.

Procedures
If you agree to participate in this research study, the following will occur:
- you will sit in a sound-treated booth in room 106 of the John Taylor Building where your speech will be recorded
- new, disposable small sensors (3 x 3 mm) will be attached with dental glue to your tongue, lips, and lower front teeth
- for 10 minutes you will either read aloud or chat with the researcher as you get used to the feeling of the sensors in your mouth
- you will read aloud sentences that will be presented on a computer screen in front of you
- you will be asked to match your rate of speech to an audio or audio/video recording of another speaker
- you will be asked to speak at half or twice your normal speaking rate
- you will hear your own voice delayed electronically (delayed feedback), which may cause you to speak differently
- total time commitment will be 60 minutes in one recording session

Risks/Discomforts
You might feel uncomfortable having electromagnetic sensors attached to your tongue, lips, and lower teeth. It is possible that some of the dental glue will remain on the tongue surface for a few minutes after the experiment is over. This may feel odd, but it will feel normal again within a few minutes. The researcher will view the surface of your tongue after removing the sensors to make sure that any traces of the glue are minimal. The single-use sensors will be thrown away after removal.

Benefits
There will be no direct benefits to you as a participant. However, we anticipate that the findings from this study will benefit the field of speech pathology by helping us design better treatments for people with speech problems.
Confidentiality
The research data will be kept on password protected computer and only the researchers will have access to the data. Before we analyze the recordings, all identifying information will be removed so that your name will not be linked to the recordings. Only summary data from groups of participants will be reported in publications and presentations. After the study the de-identified data will be kept on a password-protected computer in the researcher’s office for possible future analysis with new techniques.

Compensation
You will receive $10 for your participation, whether you finish the recording or not; compensation will not be prorated.

Participation
Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without jeopardy to your class status, grade, or standing with the university.

Questions about the Research
If you have questions regarding this study, you may contact Christopher Dromey at 133 TLRB, 801-422-6461, dromey@byu.edu for further information.

Questions about Your Rights as Research Participants
If you have questions regarding your rights as a research participant contact IRB Administrator at (801) 422-1461; A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu.

Statement of Consent
I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Name (Printed): ____________________  Signature: ____________________  Date: ________