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The Relationship Between Acoustic and Kinematic Measures of Diphthong Production

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Master of Science

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ABSTRACT

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The purpose of this study was to examine the correlation between acoustic and kinematic measures of diphthong production in 11 individuals with multiple sclerosis (MS) and 11 neurologically healthy control speakers. The participants produced four diphthongs: /ɔɪ/, /aʊ/, /aɪ/, /eɪ/. These sounds were spoken in a sentence context. Their speech audio signal was recorded with a microphone and their tongue movements were recorded with a magnetic tracking system. The first and second formants (F1 and F2) were computed with acoustic analysis software, and these signals were time-aligned with the vertical and anteroposterior magnet movement records. Pearson correlations between F1 and the magnet's vertical movement and between F2 and anteroposterior movement were computed for the individual diphthongs. The results of this study revealed an often non-linear relationship between the acoustic and kinematic measures. The degree to which the formant measures predicted the lingual movements varied across speakers and also during the on-glide, transition, and off-glide phases of the diphthongs. The findings of this study suggest that the relationship between formants and tongue movements is more complex than would be predicted from the theoretical origins of F1 and F2. Thus, researchers should be aware that acoustic parameters might not always accurately reflect the physical movements of articulators.

Keywords: acoustic analysis, kinematic analysis, multiple sclerosis, MS, formant, tongue movement, diphthong

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Table of Contents

List of Tables

List of Figures

List of Appendixes

Introduction

Researchers have used a variety of methods to characterize the key features of dysarthric speech in individuals with multiple sclerosis (MS). Perceptual analysis has been the most commonly used approach for over 50 years. However, with the development of speech measurement technologies, many researchers have adopted acoustic and kinematic methods to obtain more precise quantitative data to better understand speech in MS (Hartelius & Lillvik, 2003; Hartelius, Runmarker, & Anderson, 2000; Murdoch, Spencer, Theodoros, & Thompson, 1998; Rosen, Goozee, & Murdoch, 2008). Although these two methods examine dysarthria from different perspectives, no known studies have examined how closely their data align. The aim of the present study is to compare the data obtained from simultaneous acoustic and kinematic recordings in order to determine the degree to which the acoustic variables reflect the measured movement of the articulators in the speech of individuals with MS and a group of control speakers.

Nature of Multiple Sclerosis

Multiple sclerosis (MS) is a chronic degenerative disease and is thought to be an autoimmune disorder of the central nervous system (CNS). It usually affects the white matter of the brain stem, basal ganglia, ventricles, cerebellum, spinal cord, and optic nerves. When a person’s immune system attacks the myelin sheath that covers the nerve fibers, scarring (also called scleroses, plaques, or lesions) is left behind, leading to demyelination (National MS Society, 2006). Neurons in the brain and spinal cord transmit electro-chemical signals through their axons to communicate with other neurons. When the myelin sheath and nerve fibers are damaged, the communication between the brain and spinal cord can be impaired or interrupted (National MS Society, 2006; Smith & McDonald, 1999).

Disease Course in MS

Individuals with MS can experience one of four typical courses at different levels of severity: (a) relapsing-remitting, (b) primary-progressive, (c) secondary-progressive, and (d) progressive-relapsing.

In the relapsing-remitting course, individuals experience obvious symptoms (relapses) of neurologic dysfunction. These symptoms are then followed by periods of partial or complete recovery (remissions). During the remissions, there is no progression of the disease. More than three-fourths of patients who are diagnosed with MS present with this course (National MS Society, 2006).

In the primary-progressive course, the neurologic dysfunction slowly worsens from the onset without notable relapse or remission. Its progression rate varies, but people may experience plateaus and temporary minor improvement (National MS Society, 2006). Its onset is usually in older individuals and this disease pattern appears less often in females (McDonnell & Hawkins, 1998). It is estimated that 10% – 20 % of all MS cases exhibit the primary-progressive course (Weinshenker, 1994).

A majority of individuals with the initial relapsing-remitting disease will eventually move onto the secondary-progressive course, which is characterized by a steadily worsening of symptoms with or without remissions or plateaus (National MS Society, 2006). Once a person has reached this stage, the neurologic dysfunction worsens more quickly than it did during the relapsing-remitting course. Approximately 50% of patients with relapsing-remitting MS will have developed the secondary-progressive course within 10 years (National MS Society, 2006).

The fourth course of MS follows the relatively rare progressive-relapsing pattern. Individuals with this type of MS also experience a steady decline from the onset of the disease with clear worsening periods of relapse and remissions. They may or may not experience a remission immediately after a relapse but symptoms continue to worsen between relapses (National MS Society, 2006).

Symptoms of MS

Most individuals with MS experience multiple symptoms. A significant challenge in MS research lies in the variability with which the disease manifests itself. Its progression and symptoms vary from person-to-person, depending on where lesions occur in the CNS. However, fatigue, vertigo, numbness, gait instability, balance difficulty, cognitive problems, and dysarthria have been identified as the symptoms of MS through many studies (National MS Society, 2006).

Morris, Cantwell, Vowels, and Dodd (2002) reported that people with MS showed “a slow, short stepped, low cadence gait pattern” (p. 364) in their walking. Another study (Givon, Zeilig, & Achron, 2009) indicated significantly impaired gait parameters in individuals with MS. Freal, Kraft, and Coryell (1984) found fatigue to be a major symptom for 78% of their participants with MS. Mitchell, Beer, Yancy, Saint-Louis, and Rosberger (2008) reported a case of facial numbness accompanied by lateral rectus muscle palsy. Some researchers (Alpini, Caputo, Pugnetti, Giuliano, & Cesarani, 2001; Frohman, Kramer, Dewey, Kramer, & Frohman, 2003) have examined the diagnosis of vertigo experienced by patients with MS. In terms of speech and language, some studies have reported the prevalence, incidence, or perceptual characteristics of dysarthria in individuals with MS (Darley, Brown, & Goldstein, 1972; Hartelius, Nord, & Buder, 1995; Theodoros, Murdoch, & Ward, 2000; Yorkston, Klasner, & Swanson, 2001).

A study by Yorkston et al. (2001) identified fatigue, decreased mobility, vision, and cognition as major contributors to communication changes in people with MS. Furthermore, Yorkston et al. (2003) found in their survey that many people with MS with moderate to severe dysarthria also identified walking difficulty, fatigue, vision and hearing problems, thinking and memory issues, and reading and writing problems as challenging to them. Jenkins (2007) found mobility disorders, balance difficulty, vision problems, memory difficulties, and numbness among the participants with MS.

Impact of MS on Quality of Life

Unfortunately, MS can significantly affect a person's life as well as that of his or her family. Since it is a degenerative disease, patients with MS will eventually experience sensory, motor, and cognitive impairments at varying levels of severity. Because of this, they can be more susceptible to medical complications and may need assistive devices and support from other people, such as family members or professional care providers. The onset of MS is generally between the ages of 20 and 40 (Darley et al., 1972; National Institute of Neurological Disorders and Stroke, 2009) which is a time during which most people actively contribute to their society through work and community involvement. MS and its symptoms can limit their participation in family activities and in the broader community.

In the Yorkston et al. (2001) study, participants with MS reported limited communicative participation as a major change in their life caused by declines in speech and language, cognition, mobility, and vision along with an increase in fatigue. Specifically, in this study respondents seemed to be more concerned with their speech impairment than cognitive and physical limitations and felt that communicative problems prevented them from participating in work and their educational activities (Hartelius, Elmberg, Holm, Lövberg, & Nikolaidis, 2008). Many individuals with MS feel generally more comfortable and confident when communicative situations are easy. They feel more satisfied when the communication has been successful and when they feel connected with the partner in communicative situations (Yorkston et al., 2007).

Despite the cognitive, emotional, and physical challenges associated with MS, people with this disease may improve their condition through moderate aerobic or stretching exercises, a balanced diet with low fat and high fiber, stress management, and other complementary and alternative strategies (National MS Society, 2006).

Speech Characteristics in Multiple Sclerosis

Dysarthria is "a neurological motor speech disorder characterized by slow, weak, imprecise and/or uncoordinated movements of the speech musculature" (Hartelius et al., 2008, p. 11). Dysarthria associated with a degenerative disease, such as MS, Parkinson's disease (PD), or amyotrophic lateral sclerosis (ALS) is classified as progressive, while dysarthria following a stroke or traumatic brain injury is classified as non-progressive. For each type of dysarthria, the degree of severity ranges from mild, to moderate, to severe (Hartelius et al., 2008).

Research on Speech Deficits in MS

Individuals with MS experience not only physical symptoms of the disease, but they also suffer from speech deficits that impact their ability to communicate with others. Published accounts report the prevalence of dysarthria as ranging from 23% to 50% in individuals with MS (Darley et al., 1972; Fitz Gerald, Murdoch, & Chenery, 1987; Hartelius et al., 1995; Theodoros et al., 2000). Compared to speech disorders resulting from other neurological conditions, dysarthria in MS has not been widely investigated in the field of communication disorders. Yorkston (2007) reported that out of 148 articles about dysarthria in MS, PD, and ALS over a 10 year period, only 19 (12%) examined dysarthria in MS. Despite the limited number of speakers with MS in these studies and the variability of their speech characteristics, researchers have put significant effort into characterizing the speech production of these individuals using a variety of methods.

Characteristics of Dysarthria in MS

A number of researchers have relied on perceptual descriptions to characterize dysarthria in MS. Although MS is not always associated with a specific type of dysarthria, the most commonly identified features are those of a mixed spastic-ataxic dysarthria (Duffy, 1995; Hartelius et al., 2000; Theodoros et al., 2000; Yorkston, Beukelman, Strand, & Bell, 1999). When Darley et al. (1972) evaluated 168 individuals with MS, they found that harshness of voice, impairments to loudness, articulation, and pitch control, as well as the inability to use the voice for emphasis were prominent speech characteristics. A study by Fitz Gerald et al. (1987) examined the speech production of 23 individuals with severe MS and found evidence of pitch variation and unsteadiness, abnormal respiratory support, harsh voice quality, and prolonged intervals in 91% of the speakers. Theodoros et al. (2000) identified five speech characteristics commonly reported in studies of speech in MS. They listed “harshness, imprecise articulation/consonant production, impaired emphasis/stress patterns, impaired respiratory support, and impaired pitch variation/control” (p. 22). Hartelius et al. (2000) reported that the types of speech symptoms presented by 77 participants with MS in a clinical dysarthria testing procedure were “defective consonant articulation, vocal harshness, and prosodic difficulties, such as prolonged intervals and deviations in stress pattern and rate” (p. 174).

Relationship between Dysarthria Severity and MS

It appears that the severity of dysarthria in people with MS is linked to the severity of the disease and its course, rather than to other variables, such as age, time since diagnosis, or lesion location (Darley et al., 1972; Hartelius et al., 2000). Hartelius et al. found that the severity of dysarthria was related to disease progression and how many years an individual had been in a progressive stage. A more recent study (Yorkston et al., 2003) reported that the participants with moderate to severe dysarthria and MS experienced more severe speech problems than the participants with mild dysarthria and MS in self-report.

Acoustic and Kinematic Measures of Dysarthria in MS

Although perceptual evaluation has been the most commonly used method for studying disordered speech in patients with MS (Darley et al., 1972; Hartelius et al., 2000; Tjaden & Wilding, 2004; Yorkston, 2007; Yorkston et al, 2003), many researchers have recognized the potential benefits of acoustic analysis and have used it in their studies. Furthermore, with the advent of speech movement measurement technologies, researchers have begun to use kinematic analysis to track the movements of the articulators during speech production. Because the present study addresses the linkage between these types of speech measurement, acoustic and kinematic analyses will now be discussed in greater detail.

Acoustic Measures of Dysarthria in MS

Kent and Kim (2003) noted that due to the refinement of acoustic technologies it is possible to identify impairments in speech production that are difficult to detect with perceptual analysis in individuals with a variety of neurologic diseases. Acoustic analysis has been employed by a number of researchers in the study of speech production in MS. It enables researchers to quantify acoustic features of speech and thereby document the degeneration of motor speech function over time. In addition, clinicians can use this approach to document the effects of treatment, identify subclinical manifestations of MS, and in some cases, more confidently approach a differential diagnosis of the disease (Hartelius et al., 2000).

Researchers have analyzed several acoustic features, such as fundamental frequency (F0), speech rate and duration, formant frequencies, and sound pressure level in speech samples produced in response to different types of elicitation tasks. However, acoustic features are only an indirect reflection of the physical movements of the articulators that are affected by neurological diseases. With acoustic data, it is difficult to clearly infer which articulator is affected by the disease, how much the movement of articulators deviates from typical patterns, and which abnormal movements cause the distorted acoustic features.

Researchers often compute formant frequencies to better understand imprecise articulation because a reduction in the slope of formant transitions has been associated with the production of dysarthric speech (Kent, Weismer, Kent, Vorperian, & Duffy, 1999; Yorkston, Hammen, Beukelman, & Traynor, 1990). A formant is a resonance created by the vocal tract while speaking or singing. Formant frequencies change as the vocal tract changes its shape to articulate different vowels and consonants. Researchers usually examine the slope of the first formant (F1), second formant (F2) or both, since these measures are sensitive to changes in sound production, including dysarthria. The following studies are examples of how formant analysis has been used to better understand the effect of MS on speech production.

Tjaden and Wilding (2004) examined the effect of increased vocal loudness and decreased articulatory rate on dysarthric speech in people with MS or PD. Fifteen speakers with MS, 12 speakers with PD, and a group of 15 individuals without any neurological disease were asked to read a 192-word passage in three different conditions; slowly, loudly, and typically. The reading passage included the vowels of /i/, /ɔ/, /æ/, and /u/ and the consonants /s/, /ʃ/, /t/, and /k/ in the final position. Based on the findings of a relationship between intelligibility and vowel space area (McRae, Tjaden, & Schoonings, 2002; Weismer, Jeng, Laures, Kent, & Kent, 2001), Tjaden and Wilding measured the values of F1 and F2 for /i/, /ɔ/, /æ/, and /u/ in stressed syllables to calculate the vowel space area. They observed shallow F2 transition slopes for diphthongs produced by the participants with MS and PD and differences in the effects of rate and intensity on the F2 slopes of speakers with the two different diseases.

A recent study by Rosen et al. (2008) examined F2 range and slopes in speakers with MS to examine the effect of dysarthric speech on extreme F2 movement and typical F2 movement. These authors selected the archival recordings of 12 participants with MS from the full database and used the recordings of their reading task (Fitz Gerald et al., 1987; Murdoch, Gardiner, & Theodoros, 2000). The task was to read sentences divided into breath groups in the *Grandfather Passage*. In addition, two control groups without neurological disease took part in the study. The first group consisted of 10 people, and their data were used to identify sentences that included the greatest F2 movement in the reading passage. The second group consisted of 16 people, and their speech was used for comparisons with the MS group. The authors first measured F2 range in each utterance by defining the absolute F2 range from the steepest to the shallowest slope. Then, they calculated the absolute slope value as the change in frequency (in Hertz) over a 20 ms lag for each transition, which generated a series of instantaneous slope values over time. To reflect patterns in the instantaneous slope values, the median absolute value of the F2 slope across an entire utterance and the slope value of the 95th percentile of the absolute slope in utterance were calculated. These two measures and the mean F2 range across all sentences were used to yield typical formant changes, and with the maximum F2 range they were also used to yield extreme formant movement. The findings revealed that rapid changes in F2 were influenced by dysarthria secondary to MS and those changes were more readily observed in particular phonetic environments, such as liquids, glides, and diphthongs.

Kinematic Measures of Dysarthria in MS

Kinematic analysis examines articulatory patterns by tracking the movement of articulators, such as the jaw, tongue, and lips. Various devices have been developed over the last few decades, and these have enabled researchers to measure the movements of the articulators in both normal and disordered speech. As Barlow, Cole, and Abbs (1983) suggested, it would seem to make more sense to directly examine disordered speech movements rather than only considering the acoustic result of these movements, because impaired control of muscle contraction and movement is the more direct consequence of neuromotor abnormality.

However, some speech movement tracking systems have considerable drawbacks. For example, quantitative tongue movement data cannot be obtained by strain gauges, video recording, and LED triangulation. Using cinefluorography exposes participants to the danger of radiation. The complexity and cost of computerized X-ray microbeam, magnetic resonance imaging (MRI) tagging, ultrasound, and electromagnetic tracking system have limited their use in many laboratories (Dromey, Nissen, Nohr, & Fletcher, 2006). Recently, a jaw-tracking system that uses a single, permanent magnet has been used to quantify tongue movements during speech (Dromey et al., 2006; Nissen, Dromey, & Wheeler, 2007).

Murdoch and colleagues directly tested lingual force generation in dysarthric speakers with MS (Murdoch et al. 1998). They used a rubber-bulb pressure transducer that was introduced in an earlier study (Murdoch, Attard, & Ozanne, 1995). A total of 16 adults with MS and a control group matched for age, gender, and education level participated in this study. The participants performed non-speech tasks, such as pushing the rubber bulb up against the hard palate as forcefully as they could and pushing the rubber bulb as many times as possible during a limited time period. Maximum tongue pressure, repetition of maximum tongue pressure, fine tongue pressure, fast-rate maximum tongue pressure, and sustained tongue pressure were measured. The authors found significant differences in the tongue function of the participants with MS and individuals in the control group for all lingual variables except fine tongue pressure, but found no significant differences in measures of lip function. Murdoch et al. also found that all of their participants with MS showed reduced maximum pressure, fewer repetitions, and decreased endurance in tongue measures compared to the individuals in the control group.

Similarly, a more recent study by Hartelius and Lillvik (2003) reported significantly affected tongue (but not lip) function in the dysarthric speech of patients with MS. However, this study did not include any acoustic analysis. The authors compared the dysarthria test scores on lip and tongue function obtained by administering an adapted version of the protocol used by Darley et al. (1972).

In a case study by Murdoch et al. (2000), electropalatography (EPG) was used to examine articulatory dysfunction in a person with MS by tracing tongue-to-palate contacts during speech production. One person with MS and four individuals without a neurological disease participated in this study. They wore an artificial acrylic palate which was customized to fit their hard palate; this pseudopalate contained 62 miniature disc electrodes situated at specific anatomic landmarks. Each individual was asked to repeat a list of six words (CVC structure) that were randomly presented five times in the list; the words were *tar, darn, sarge, tsar, lark,* and *nark*. The authors analyzed the placement and timing of the contacts between the tongue and palate in the initial consonants. The findings showed that the person with MS demonstrated the correct placement of the tongue relative to the palate, but with articulatory overshooting (a larger than expected movement of the articulators). In addition, the person with MS displayed deviations in duration, such as an increased closure duration for /l/ and /n/ and a shorter release phase for /t/ and /d/.

Summary

Studies of dysarthria in MS have relied on various techniques, including perceptual, acoustic, and kinematic analyses. They have revealed a number of insights into the characteristics of disordered speech in MS. Acoustic and kinematic analyses have provided quantitative data to complement previous perceptual accounts. Acoustic analysis focuses on the consequences of speech movements, while kinematic analysis focuses on the speech movement that is the source of these acoustic features. Therefore, it would be valuable to examine the relationship between the data from these two measurement methods, since acoustic measures are generally accepted as indirectly reflecting the movements that underlie the production of speech sounds.

Since F1 reflects the vertical movement of the tongue, and F2 reflects anteroposterior tongue movement (Ferrand, 2007), the goal of the present study was to compare the results of these two acoustic variables and the magnetically tracked movements of the tongue that they are assumed to represent. There are several factors that could potentially influence the relationship between these two types of signal. One of these would be motor equivalence (Hughes & Abbs, 1976), whereby slightly different vocal tract configurations across individual speakers can nevertheless result in the production of a perceptually equivalent phoneme. In other words, there can be more than one way to produce a similar result as movement in one part of the vocal tract co-occurs with adjustments elsewhere that combine to produce the target sound. A further influence on the kinematic-acoustic linkage would be coarticulation, because lingual movements for target sounds can be influenced by the production of neighboring sounds in the context of words or sentences (e.g., Beddor, 2009; Ohala, 1993; Story, 2009). Finally, according to the quantal theory of speech (Stevens, 1989; Stevens & Keyser, 2010), the relationship between acoustic and kinematic parameters is not always linear, in that the same degree of articulator displacement in one position may have a much larger influence on acoustics than the same displacement at a different point along its trajectory.

The objective of the current study was to examine the correlation between the results of acoustic analysis and kinematic analysis in the speech of individuals with MS and a group of age-matched control speakers in order to determine the extent to which the acoustic measures accurately predicted the lingual movements.

Method

The current study was part of a larger research effort. In the process of gathering speech samples, language samples were also collected on the same day from participants with MS and from participants without MS as a control group and were analyzed for the purposes of other research projects.

Participants

A total of 11 individuals diagnosed with MS voluntarily participated in this study. In order to protect patient privacy and to comply with HIPAA regulations, the initial contact with the individuals was made through their neurologist's office. Potential participants were sent a form letter (see Appendix A) describing the study, and were asked to respond to the researchers via mail or telephone if they were interested. Those who expressed interest in participating in the study were contacted by telephone, and the researchers conducted an initial screening interview by asking questions. The questions are listed in Appendix B.

All the participants had been diagnosed with MS for at least one year. All were native speakers of English and reported no speech or language issues prior to the onset of MS. In response to the telephone interview questions, six of the participants reported dysarthria-like speech experiences during MS relapses. However, no obvious signs of dysarthria were noted during the recording sessions of these individuals. The severity of dysarthria was perceptually judged by two researchers who were graduate students from the Communication Disorders program at Brigham Young University. They reported that nine of the participants with MS had normal speech at the time of their recordings. One individual was judged to have mild dysarthria and another was perceived to have moderate dysarthria. All the participants with MS reported their disease course as relapsing-remitting, secondary-progressive, or primary-progressive MS. Table 1 shows the demographic information for these participants.

Table 1

Demographic Information

Speaker	Age (years)	Gender	Years Post-Diagnosis	Pattern of MS*	Severity of Dysarthria
1	54	F	9	RR	normal
2	38	F	9	RR	normal
3	51	M	27	RR	normal
4	39	F	3	RR	normal
5	41	F	3	SP	normal
6	50	F	11	PP	normal
7	29	M	7	RR	normal
8	29	M	15	SP	moderate
9	37	F	3	RR	normal
10	40	F	11	RR	normal
11	60	M	27	RR	mild

*Patterns of MS are identified as follows: RR = relapsing remitting; SP = secondary progressive; PP = primary progressive.

Eleven individuals with no neurological disease participated in this study as a control group matched for age and gender. All participants were informed of the purpose of the study and given the opportunity to ask questions of the researchers. After their questions were answered, they signed an informed consent document approved by the University IRB shown in Appendix C.

Speech Tasks

Each participant completed four speech tasks in the following order: maximum sustained vowel phonation, diadochokinesis (DDK), sentence repetition, and passage reading. For the maximum sustained vowel phonation task, each participant was asked to take a deep breath and produce the vowel /ɑ/ at a comfortable loudness and pitch for the maximal time he or she could hold. They repeated this task three times. For the DDK task, each participant was instructed to repeat each /pʌ/, /tʌ/, and /kʌ/ as an alternating motion rate production (AMR) and also to repeat /pʌtʌkʌ/as a sequential motion rate (SMR) series. The participants were asked to repeat the syllables as quickly and smoothly as possible after the researcher's demonstration was given. For the sentence reading task, each participant was asked to read two sentences five times at a normal speech rate and loudness: *The boot on top is packed to keep* and *The boy gave a shout at the sight of the cake*. Finally, for the passage reading task, each participant was instructed to read the *Rainbow Passage* (Fairbanks, 1960) at a normal reading rate and loudness.

Equipment

During each speech task, the acoustic signal was recorded into a Dell computer via a microphone (AKG C 2000 B) with a mouth-to-microphone distance of 15 cm. The acoustic signal passed through a Samson Mix Pad 4 preamplifier and then a Frequency Devices 9002 low pass filter. A Windaq 720 interface was used to digitize the acoustic signal from the microphone, and a sound level meter (Larson Davis 712) was used to measure speech intensity. An adapted BioResearch Associates JT-3 jaw tracking instrument was used for measuring tongue movement as described in the study by Dromey et al. (2006).

Procedure

As noted earlier, participants' speech and language samples were collected for different research purposes. As part of the larger study, participants were asked to perform the same tasks in the morning and in the afternoon. Morning and afternoon recordings took place in a counterbalanced sequence to minimize any potential practice effects. Half of the participants were recorded in the morning and in the afternoon on the same day; half were recorded in the afternoon of one day and in the morning of the next day. In addition, a 20-minute language sample recording took place before or after the speech sample recording in random order to counterbalance potential fatigue effects.

Each participant sat in an Acoustic Systems sound booth on a chair in front of the microphone. Using cyanoacrylate glue, the researcher attached a small magnet to the upper surface of the participant's tongue, approximately 1 cm posterior to the tip. A BioResearch Associates JT-3 movement tracking headset was positioned on the participant's head to track the movement of this magnet, as described by Dromey et al. (2006). Sentence and passage reading materials were provided on a stand in front of the participants. The same procedure was performed in all recording sessions. Only speech samples from the sentence reading from the afternoon recordings were analyzed for the current study.

Data Analysis

The multi-channel file which included the audio and magnet movement data was opened in the Windaq Waveform Browser application (version 2.49; DATAQ Instruments, 2006). Within the longer recording of the session, this file contained five repetitions of the sentence *The* *boy gave a shout at the sight of the cake*. The first three repetitions were selected for analysis. From the recorded channels, only those for the audio, vertical and anteroposterior magnet movements were exported as a new binary file. This new file was then imported into a custom application in MATLAB (The Mathworks, 2009), which allowed the researcher to segment the individual diphthongs, /ɔɪ/, /aʊ/, /aɪ/, and /eɪ/ from the time-aligned audio and magnet movement data. The audio channel of each segmented diphthong was saved into a short wav file, and these files were subsequently read into PRAAT acoustic analysis software (version 5.0.47; Boersma & Weenink, 2007) to compute F1 and F2. Figure 1 shows the formant tracks for the diphthong /ɔɪ/ by an individual from the control group, and Figure 2 shows the formant tracks for the same diphthong by another individual. As can be seen, the formants above F3 cannot always be reliably tracked. PRAAT wrote out a text file listing the formant values from each diphthong at 1 ms intervals.

These text files were then imported back into MATLAB, and the F1 and F2 formant values were time-aligned with the vertical and anteroposterior magnet movement records. Finally, Pearson correlations between F1 and the magnet’s vertical movement and between F2 and anteroposterior movement were computed for the individual diphthongs. A continuous correlation function was computed by generating a sliding 50 sample window that computed the correlation between the acoustic and kinematic movement records point-by-point along the entire diphthong. This allowed an observation of changes in the relationship between the two traces over time.

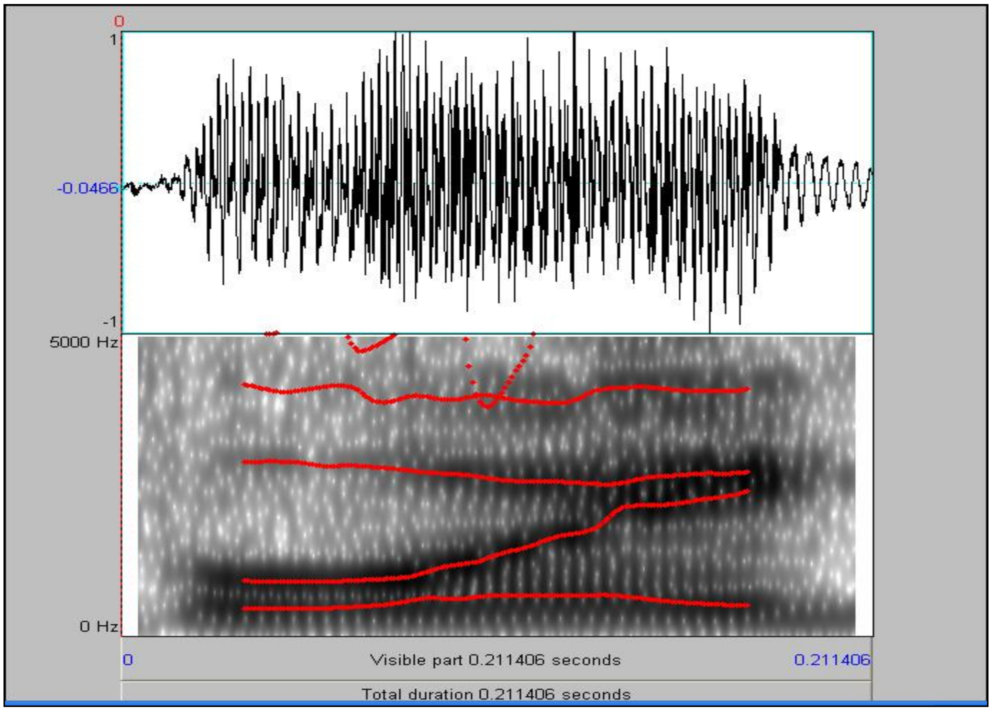

Figure 1. Formant tracks for /ɔɪ/ produced by a control group speaker in PRAAT.

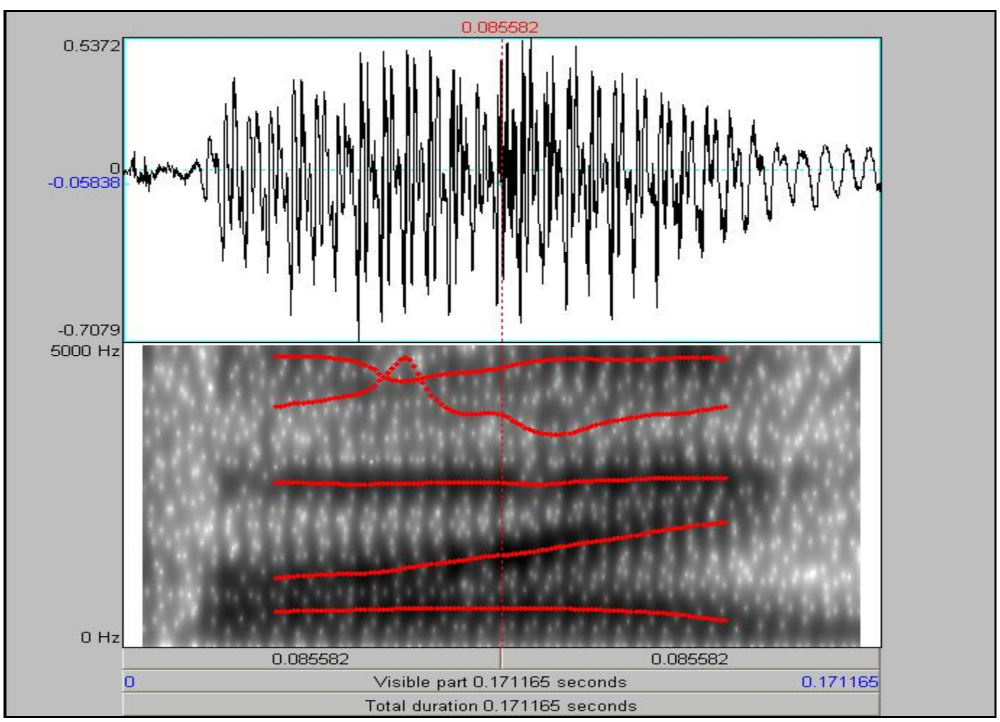

Figure 2. Formant tracks for /ɔɪ/ produced by a control group speaker in PRAAT.

Statistical Analysis

Descriptive statistics were used to quantify the strength of the correlation between the kinematic and acoustic signals during diphthong production in this study. Mean values for the correlations during the on-glide, transition, and off-glide of each diphthong were computed. A repeated measures analysis of variance (ANOVA) was used to test for differences in the strength of the correlation across these three temporal segments of the diphthong. Concurrent contrasts were used to reveal which segment differed from its neighbor in the strength of the acoustic/kinematic correlation. All statistical testing was completed with SPSS 16, and because of the non-normal distribution of correlations, ANOVA and contrast tests were computed on Fisher-z transformed variables.

Results

The means and standard deviations of the correlations between the acoustic and kinematic variables during the diphthong on-glides, transitions, and off-glides will be presented first. Then the results of the inferential statistics, including repeated measures ANOVA and concurrent contrasts, will be outlined. The correlations for the on-glide, transition, and off-glide for the four diphthongs were evaluated on the basis of the plots of individual participants. The general trends for each diphthong will be described.

Because no significant differences were found between the speakers with MS and the control group, the results represent the combined data from both groups. The lack of differences between the groups might have been due to the mild nature of the speech impairment in the speakers with MS.

Table 2 shows the means and standard deviations of the correlations between the F1 and vertical tongue movement and between the F2 and anteroposterior tongue movement during the diphthong on-glides, transitions, and off-glides.

Table 2

Means (and Standard Deviations) of the Correlations between the Acoustic and Kinematic Variables

	On-glide	Transition	Off-glide
/ɔɪ/ F1	.354 (.427)	.002 (.271)	-.720 (.386)
/ɔɪ/ F2	.456 (.308)	.842 (.232)	.767 (.374)
/aʊ/ F1	-.702 (.285)	-.243 (.266)	-.639 (.292)
/aʊ/ F2	.672 (.364)	.381 (.328)	-.067 (.476)
/aɪ/ F1	-.513 (.271)	-.611 (.330)	-.829 (.247)
/aɪ/ F2	-.319 (.672)	.279 (.428)	.397 (.454)
/eɪ/ F1	-.118 (.377)	-.418 (.338)	-.487 (.406)
/eɪ/ F2	.207 (.320)	.262 (.318)	.313 (.359)

Repeated measures ANOVA tests revealed statistically significant overall differences across the three diphthong components (on-glide, transition, off-glide) for the correlations between the acoustic and kinematic variables. These differences were found for all four diphthongs at an alpha level of .05 with one exception; no significant difference was revealed across the on-glide, transition, and off-glide for the correlation between the F2 and anteroposterior tongue movement for the production of /eɪ/ (see Table 3).

When the correlations between the acoustic and kinematic variables for the on-glides versus the transitions for each diphthong were compared through concurrent contrasts, significant differences were found for the /ɔɪ/ F1, /ɔɪ/ F2, /aʊ/ F1, /aʊ/ F2, /aɪ/ F2, and /eɪ/ F1. In comparing the transitions with the off-glides, significant differences were found for the /ɔɪ/ F1, /aʊ/ F1, /aʊ/ F2, and /aɪ/ F1 (see Table 3).

Table 3

Repeated Measures ANOVA and Concurrent Contrast Results Comparing On-glides, Transitions, and Off-glides for the Four Diphthongs

	RM ANOVA		Contrasts	
	F-ratio	*p*-value*	on vs. trans *p*-value	trans vs. off *p*-value
/ɔɪ/ F1	53.371	<.001	.001	<.001
/ɔɪ/ F2	19.829	<.001	<.001	.573
/aʊ/ F1	15.893	<.001	<.001	<.001
/aʊ/ F2	20.537	<.001	.001	.001
/aɪ/ F1	20.592	<.001	.137	<.001
/aɪ/ F2	10.127	.003	<.001	.244
/eɪ/ F1	7.736	.001	.004	.279
/eɪ/ F2	.709	.498	.520	.490

*$p < .05$

Relationships between Formants and Tongue Movements

Correlations for /ɔɪ/

F1 and vertical tongue movement. For the relationship between the F1 and vertical movement of the tongue, a negative correlation was predicted because F1 should decrease as the tongue position elevates during the production of the diphthong /ɔɪ/. However, during the on-glide, only six participants showed a weak negative correlation, and during the transition, the correlation varied between modest positive and negative values across individuals (see Figure 3).

As presented in Table 2, for the /ɔɪ/ F1 most of the participants demonstrated a strong negative correlation during the off-glide.

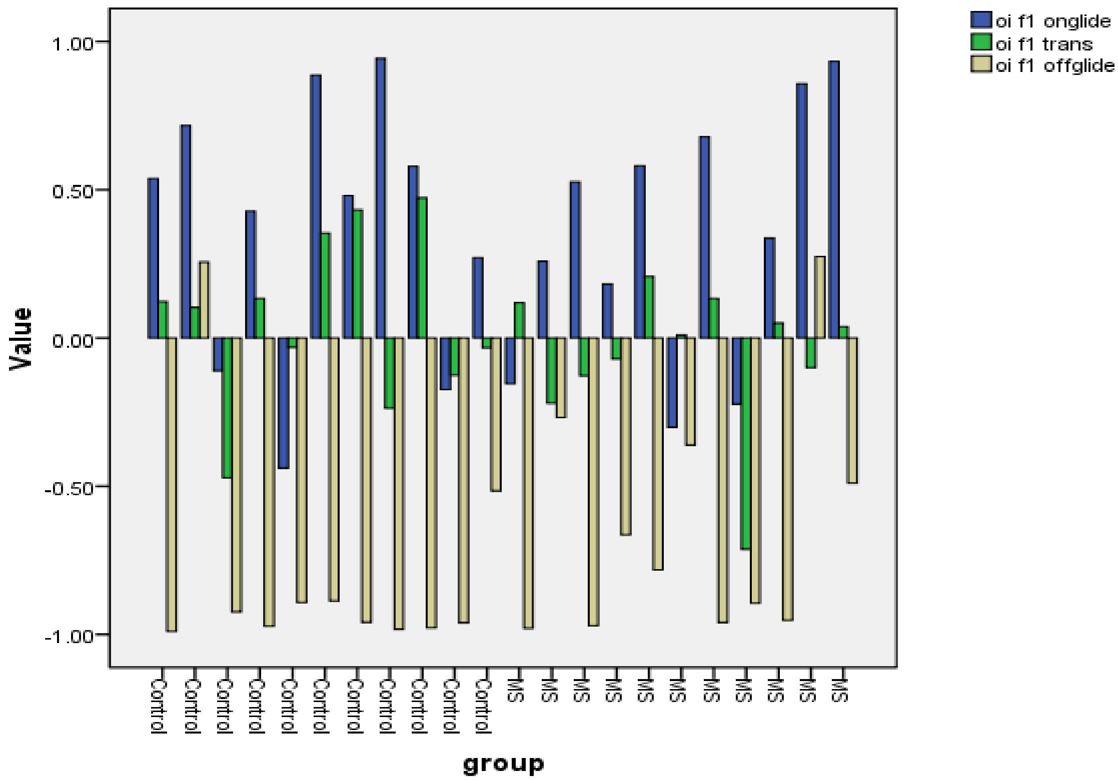

Figure 3. Individual speaker correlations for /ɔɪ/ between F1 and vertical movements.

F2 and anteroposterior tongue movement. A positive correlation was predicted for the relationship between the F2 and anteroposterior tongue movement because the F2 should increase as the tongue moves forward during the production of /ɔɪ/. The result showed that most participants displayed a positive correlation varying from weak to strong, except three individuals who showed a negative correlation at some point of their production as presented in Figure 4. The correlations during the transition and off-glide were stronger than the correlation during the on-glide (see Table 2).

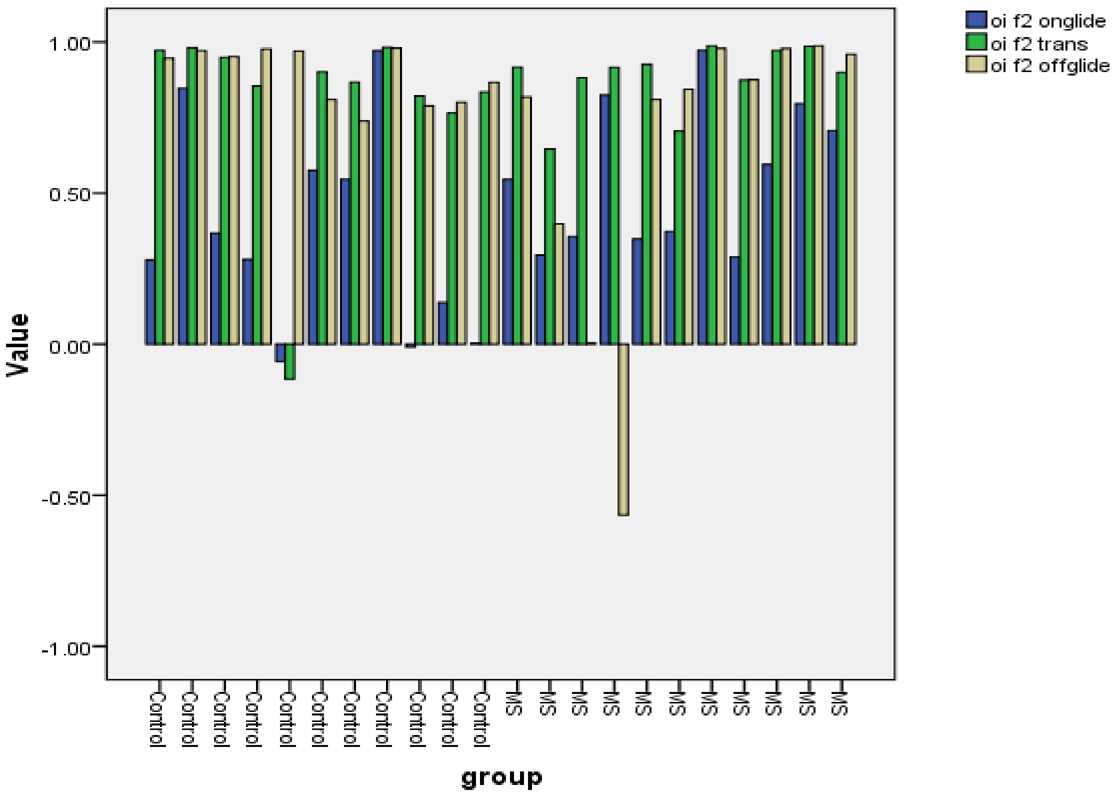

Figure 4. Individual speaker correlations for /ɔɪ/ between F2 and a-p movements.

Correlations for /aʊ/

F1 and vertical tongue movement. A negative correlation was predicted for the relationship between the F1 and vertical tongue movement because the F1 increases as the tongue position elevates during /aʊ/ production. As seen in Figure 5, all participants displayed a negative correlation during the on-glide, transition, and off-glide, except four individuals who had a positive correlation during the transition and one individual who had a positive correlation during the off-glide. The negative correlations during the on-glide and off-glide were stronger than the correlation during the transition, and the overall negative correlation was strong (see Table 2).

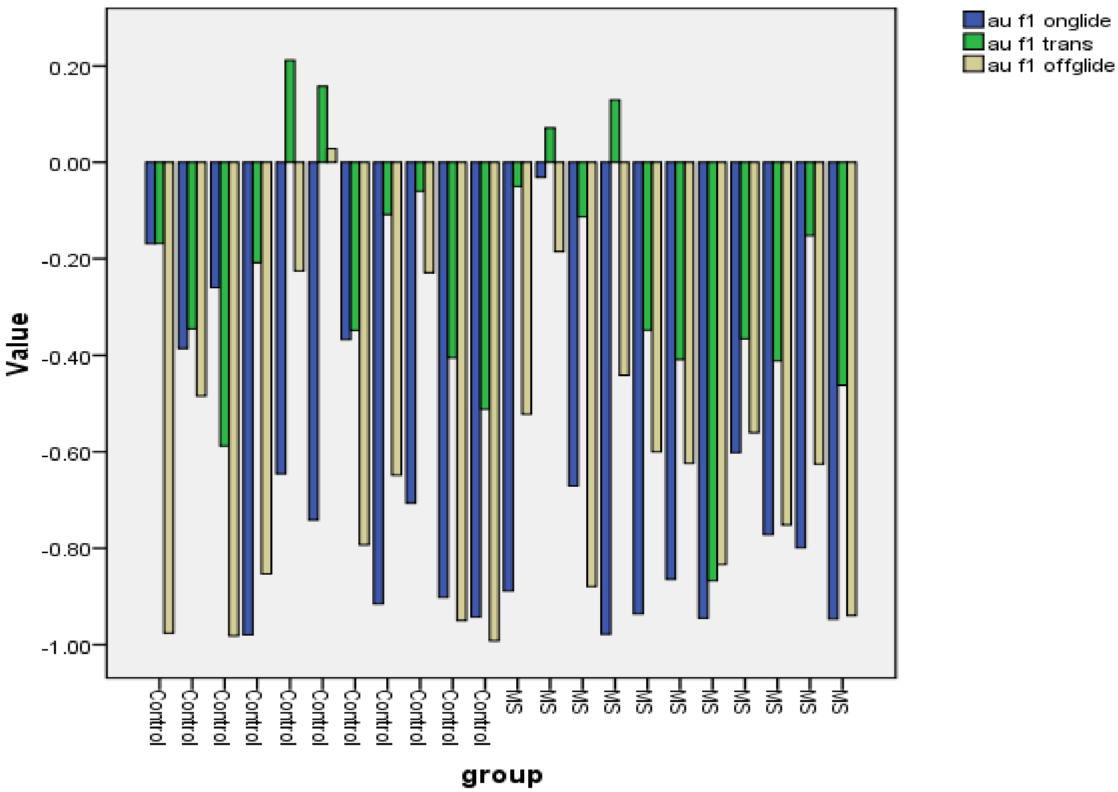

Figure 5. Individual speaker correlations for /aʊ/ between F1 and vertical movements.

F2 and anteroposterior tongue movement. Substantial changes in the F2 would not be anticipated during the production of /aʊ/ because the primary movement is vertical for this diphthong. Thus, a strong relationship between the F2 and anteroposterior tongue movement would not be predicted. Most of the participants displayed a positive correlation during the on-glide and transition except two individuals who showed a strong negative correlation (see Figure 6). A particularly strong positive correlation for the /aʊ/ F2 was seen during the on-glide (see Table 2). However, during the off-glide, the correlation did not follow a clear pattern, with individual speakers showing either positive or negative correlations. The correlation during the on-glide was stronger than the correlation during the transition.

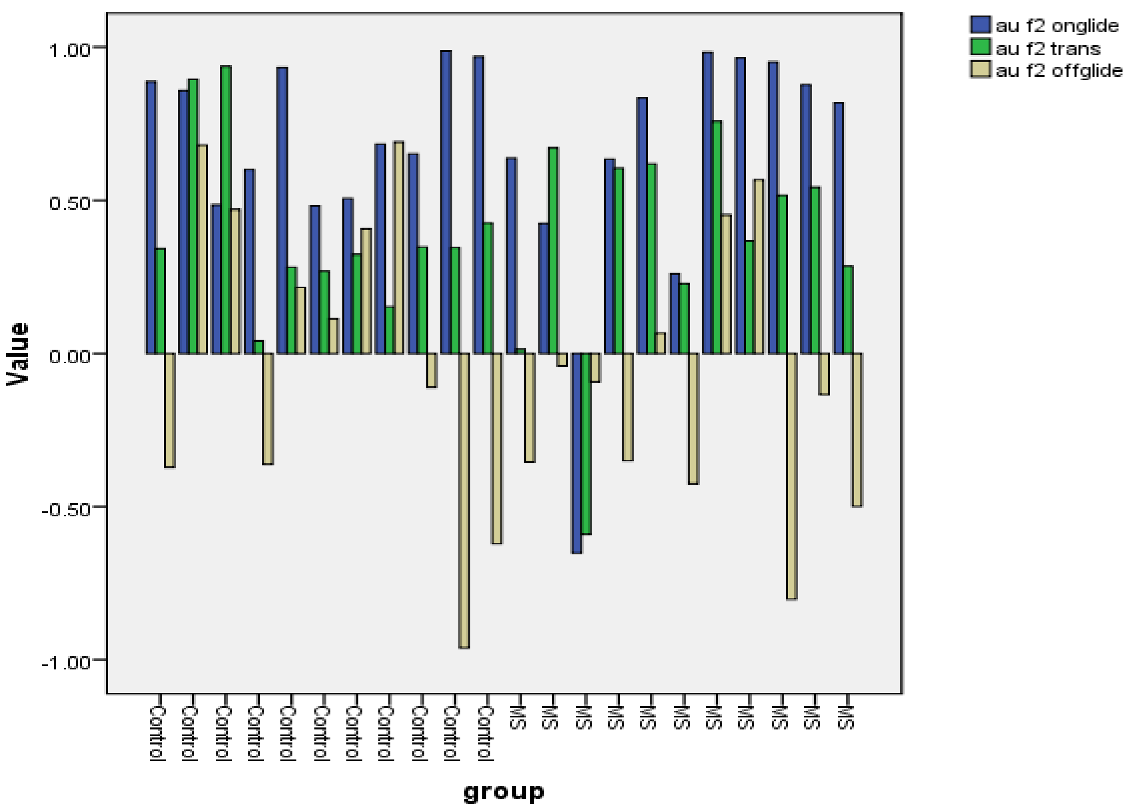

Figure 6. Individual speaker correlations for /aʊ/ between F2 and a-p movements.

Correlations for /aɪ/

F1 and vertical tongue movement. The prediction for the relationship between the F1 and vertical tongue movement was a negative correlation since the F1 theoretically decreases as the tongue position elevates during /aɪ/ production. The results matched the prediction, showing a negative correlation overall, except for three individuals whose correlations were positive during the transition or off-glide as displayed in Figure 7. The strength of the negative correlation increased from the on-glide, to the transition, to the off-glide. There was variability across individuals in the strength of the correlations during the on-glide and transition.

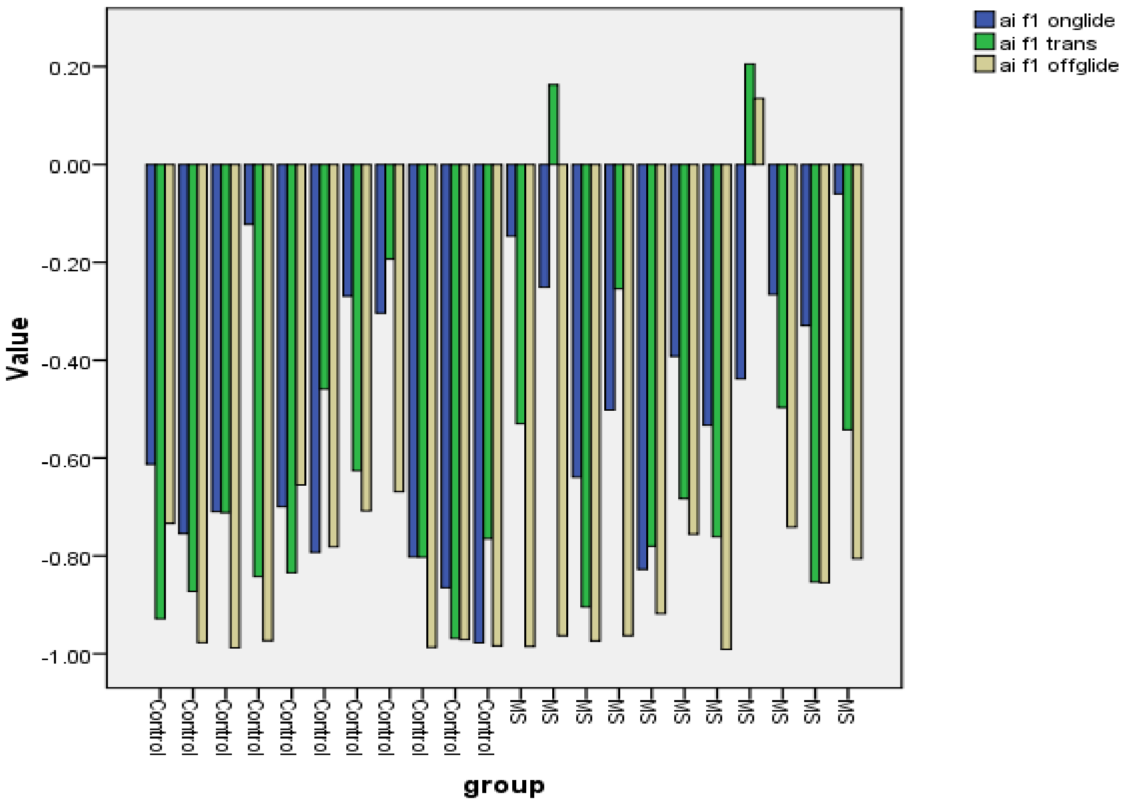

Figure 7. Individual speaker correlations for /aɪ/ between F1 and vertical movements.

F2 and anteroposterior tongue movement. A positive correlation was predicted for the relationship between the F2 and anteroposterior tongue movement since the F2 normally increases as the tongue position moves forward during /aɪ/ production. However, the results did not confirm this predicted relationship between the acoustic and kinematic measures. Most of the participants demonstrated a positive correlation varying from weak to strong during the transition and off-glide. More than half of the participants showed a strong negative correlation during the on-glide (see Figure 8).

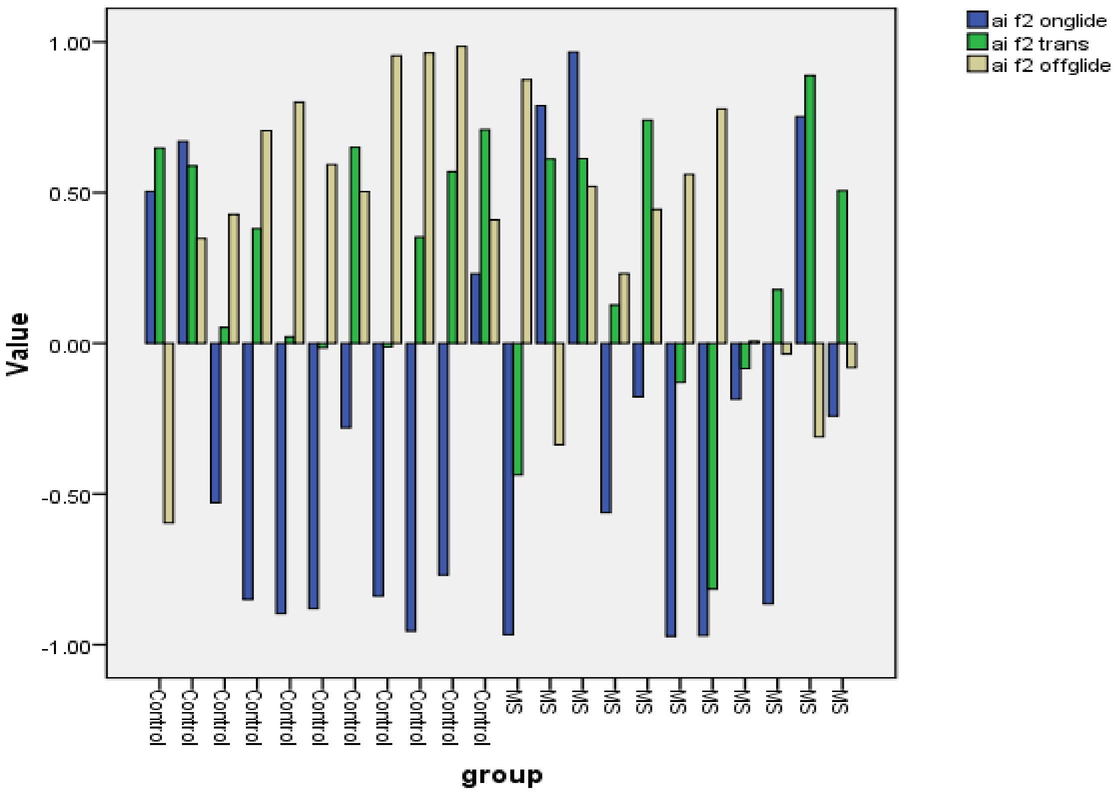

Figure 8. Individual speaker correlations for /aɪ/ between F2 and a-p movements.

Correlations for /eɪ/

F1 and vertical tongue movement. The correlation between the F1 and vertical tongue movement was predicted to be negative, because the F1 decreases as the tongue position elevates during the production of /eɪ/. The result indicated that during the on-glide the correlation did not follow a clear pattern, and the individual speakers showed either positive or negative correlations as presented in Figure 9. As seen in Table 2, the strength of the negative correlation increased from the on-glide to the transition to the off-glide, but the values remained weak overall. Also, there was variability across individuals in the strength of the negative correlation during the transition except for three speakers who presented a weak positive correlation and during the off-glide and for two speakers who showed a positive correlation.

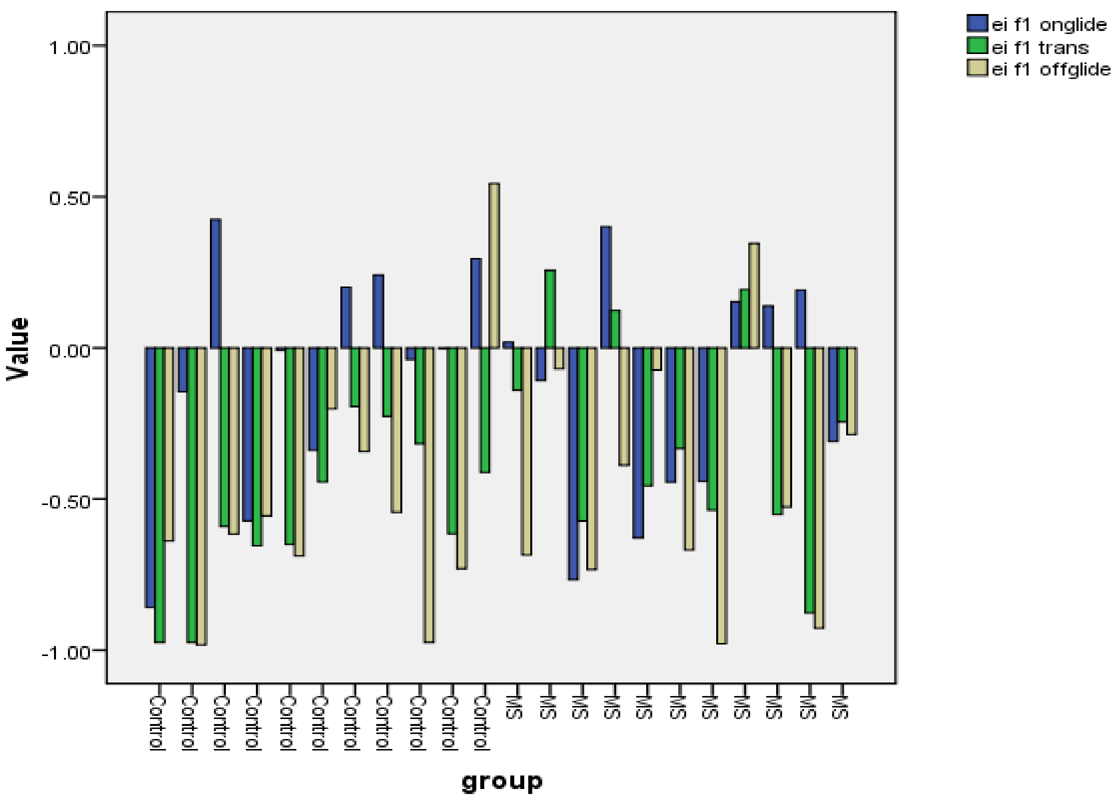

Figure 9. Individual speaker correlations for /eɪ/ between F1 and vertical movements.

F2 and anteroposterior tongue movement. No strong relationship was anticipated during the production of /eɪ/ for the same reason provided for the production of /aʊ/, namely that the movement of the tongue would be primarily vertical. The /eɪ/ F2 followed the same pattern as the /eɪ/ F1, except that weak positive correlations were seen. However, a positive correlation was observed showing variability in its strength across individual speakers although some of them displayed a negative correlation during the on-glide, transition, or off-glide (see Figure 10).

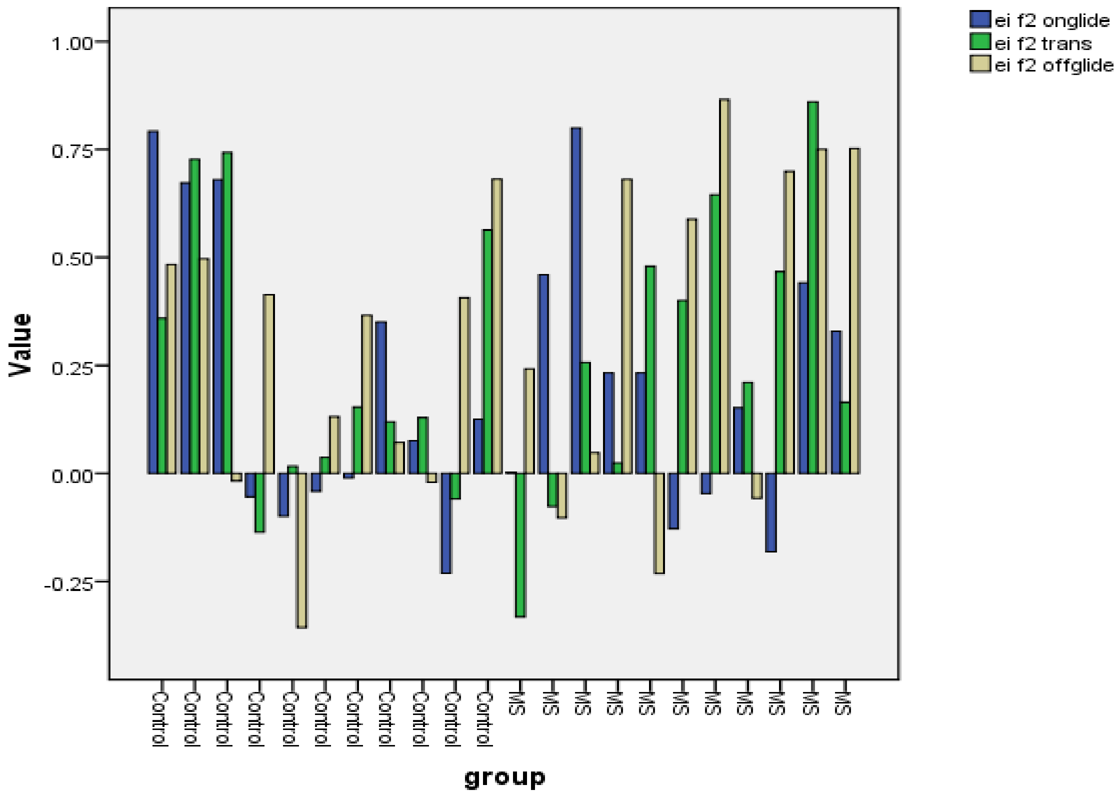

Figure 10. Individual speaker correlations for /eɪ/ between F2 and a-p movements.

Variability in Acoustic-Kinematic Correlations

Figure 11 shows an example of the predicted strong correlation between F2 and anteroposterior tongue movement over time during the production of /ɔɪ/. In contrast, Figure 12 shows how the predictive power of the acoustic measure can be weak for some sounds or individuals. It displays the F1 change and vertical tongue movement with their correlation over time during the production of /eɪ/. Even though the tongue movement appeared steady, the acoustic data showed an irregular pattern over time, which led to a weak correlation.

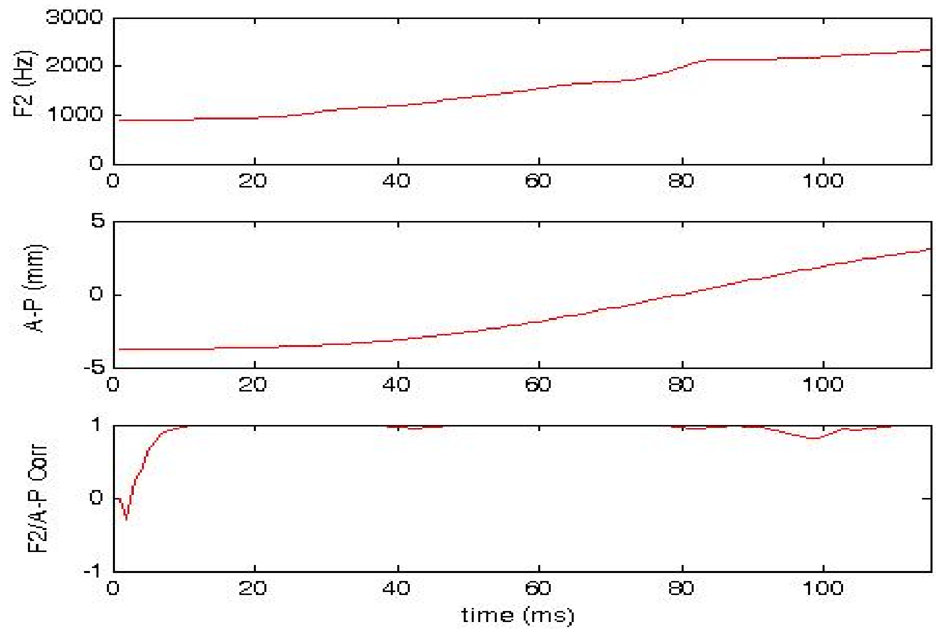

Figure 11. F2 (upper panel), a-p tongue movement (middle panel), and the correlation between them (lower panel) during the production of /ɔɪ/ by a control group speaker.

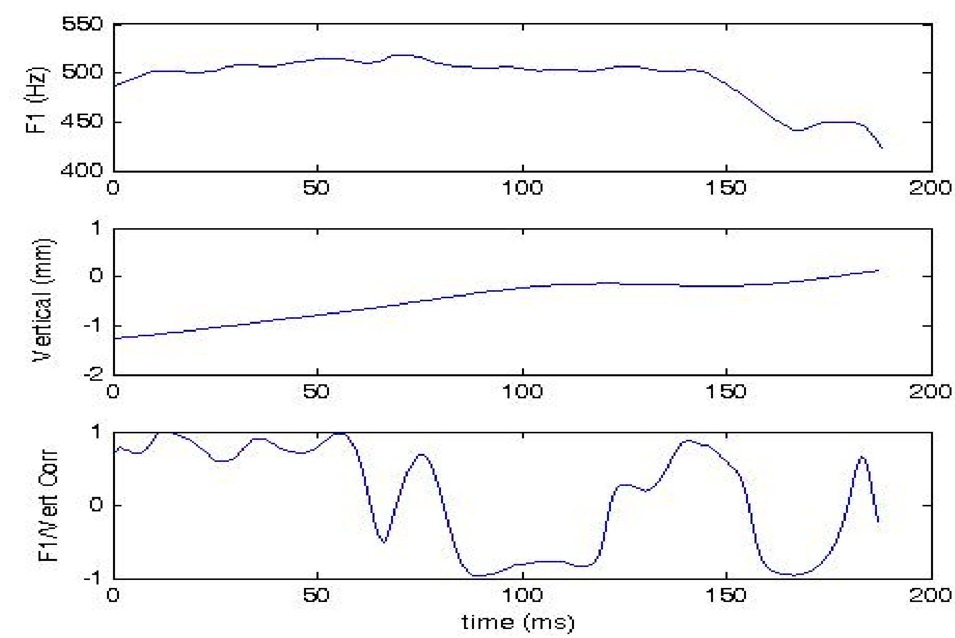

Figure 12. F1 (upper panel), vertical tongue movement (middle panel), and the correlation between them (lower panel) during the production of /eɪ/ by a control group speaker.

Discussion

The purpose of this study was to investigate the correlation between acoustic and kinematic variables in the speech of individuals with MS and neurologically healthy individuals. The participants produced four target diphthongs embedded in a sentence, and their F1 and F2 were extracted to correlate with their vertical and anteroposterior tongue movements during the production of the diphthongs.

Acoustic-Kinematic Relationships

Correlations for /ɔɪ/

Based on the results of the present study, F1 was not a good predictor of the vertical tongue movement during the on-glide and transition because the anticipated negative correlation between the acoustic and kinematic variables was not found. Instead, the correlation was either positive or close to zero. Only during the off-glide was the predicted association found, where decreasing F1 values were predictive of increasing tongue height. It could be speculated that the on-glide and transition were influenced by coarticulation with the initial consonant /b/ of *boy* in the current context. Alternatively, it is possible that the linkage between lingual movement and the resultant acoustic signal was nonlinear during the early phases of the diphthong. The widely held view is that F1 decreases as the tongue is elevated because this movement enlarges the pharyngeal space where F1 resonates. However, this general principle may be too simplistic to account for other acoustic interactions that influence the frequency of F1 during diphthong production.

F2, however, was a good predictor of the anteroposterior tongue movement because it showed an overall strong positive correlation with the magnet tracker signal as predicted. Based on the English vowel chart created by Peterson and Barney (1952), the tongue has to move a greater distance forward than upward to produce /ɔɪ/, which is the combination of a mid-back vowel /ɔ/ and a high-front vowel /ɪ/. It is possible that this larger tongue movement was responsible for the more predictable association between F2 and the forward movement.

Correlations for /aʊ/

Consistent with the theoretical prediction, F1 and the vertical tongue movement showed a strong negative correlation during the on-glide, transition, and off-glide components of this diphthong. It is possible that the relatively large tongue movement involved in the production of this sound could have contributed to the more predictable relationship between F1 and the vertical tongue movement, since correlations are more easily detectable when the data range is large (Glass & Hopkins, 1984).

Because of the modest range of the anticipated anteroposterior tongue movement (both components of the diphthong are articulated relatively far back), a strong acoustic-kinematic correlation was not anticipated. Nevertheless, a strong positive correlation was found during the on-glide. During the transition the positive correlation weakened, and it changed to a negative correlation during the off-glide. It could be speculated that although there is in theory little anteroposterior tongue movement, in practice there might have been an active tongue movement at the beginning of the sound. When /aʊ/ is produced in the context of the word *shout*, the more anterior tongue placement for /ʃ/ is followed by a backward movement for /a/ and /ʊ/. Thus, coarticulatory influences might have led to a greater anteroposterior tongue movement during the on-glide. It should also be recognized that the lip rounding for /ʊ/ increases the length of the vocal tract, which influences all formant frequencies. Also, it may be overly simplistic to attribute F2 changes solely to anteroposterior movements, since F2 is also influenced in part by the height of the tongue (Ferrand, 2007). It is possible that a combination of these phenomena contributed to changes in F2, and thus resulted in the unanticipated correlation patterns during the transition and off-glide.

Correlations for /aɪ/

The F1 was a good predictor of the vertical tongue movement because strong negative correlations were found between them, confirming the prediction during all three phases of the diphthong. The substantial vertical tongue movement might have been a factor in this finding.

Contrary to the theoretical prediction, F2 did not unambiguously reflect the anteroposterior tongue movement. Most individuals showed a negative correlation during the on-glide and varying levels of positive correlation during the transition and off-glide. The high degree of inter-speaker variability is apparent in Figure 8. The reason for these differences across speakers is unclear. However, it is possible that differences in speaking style that are not critical to listeners' comprehension could have contributed to the variability across individuals in the correlation.

Correlations for /eɪ/

The F1 was not a clear predictor of the vertical tongue movement during the on-glide. For the transition and off-glide there was a stronger trend on average, although individual speakers differed widely. F2 was only weakly associated with the anteroposterior tongue movements. Both the vertical and anteroposterior movements of the tongue for /eɪ/ are relatively smaller than for the other three diphthongs because the places of the articulations of each sound in /eɪ/ are located close to each other in the oral cavity. This could have made both formants less reliable predictors of the tongue movements because of the limited data range (Glass & Hopkins, 1984).

Another possible explanation is that some people produced the monophthong /e/ where others produced the diphthong /eɪ/ in the word *cake*. This phenomenon could have occurred for some of the participants when they were producing a target sound in the context of the experimental sentences.

General Discussion

With a few exceptions the correlations between the acoustic and kinematic variables did not appear to show a consistently linear relationship during the production of the four diphthongs. In a number of cases there was either a weak correlation or one that was opposite to what was predicted. Furthermore, there was a significant degree of variability in the strength of a correlation across the on-glide, transition, and off-glide for some of the sounds even within individuals. Among the few cases where the theoretical predictions were met, there was a strong negative overall correlation for /aʊ/ F1 and /aɪ/ F1, and a strong positive correlation for /ɔɪ/ F2 when there was a relatively large lingual movement. However, the correlations between the acoustic and kinematic data were not always consistent throughout the production of each diphthong. Each phase (on-glide, transition, and off-glide) showed a statistically significant difference in the correlation from its neighboring phase, which makes it impossible to rely on the assumption of a simple, linear association between the tongue movement and the formant tracks during the production of these diphthongs. For example, in the case of /ɔɪ/ F1, the correlation during the transition was close to zero while the correlation during the off-glide was strongly negative. For /aʊ/ F2 the correlation during the off-glide was negative while the correlation during the on-glide was highly positive.

The findings of the present study can be considered in the context of the quantal theory of speech (Stevens, 1989; Stevens & Keyser, 2010). According to this theory, there are hypothetical regions of articulatory movement for which there is little change in the acoustic parameters associated with that movement. Conversely, there can be other regions along the movement continuum that result in large acoustic changes. In other words, for these particular movements the acoustic parameters (formant frequencies in the present study) are sensitive even to a small change in the kinematic parameter (i.e., lingual movement). Thus, at some points a substantial change occurs in speech in response to a minor vocal tract adjustment. As Stevens explains, “discontinuous attributes of the acoustic signal occur in spite of rather continuous movements or changes in the articulatory parameters” (p. 5). Stevens proposed that there are various factors, such as the place of constriction or lip rounding, which can lead to a quantal relationship between acoustic and kinematic parameters. In the current study, it could be speculated that even though tongue movements (one of the articulatory parameters) were continuous, at some point the formant frequency (one of the acoustic parameters) was more sensitive to changes in the tongue movement and changed more substantially. As a result, a non-linear relationship was observed between them.

Ferrand (2007) noted that F2 is affected not only by tongue advancement but also by tongue height, which also directly influences F1. F2 decreases as tongue height decreases; the high front vowel /i/ has the highest F2, and the low front vowel /æ/ has the lowest F2 of the front vowels. In addition, formant frequencies for back vowels decrease when the length of the oral cavity increases due to lip rounding. Ferrand also explained that this pattern does not apply to the central vowels “due to the neutral position of the tongue for these vowels” (p. 206). Therefore, F2 cannot be interpreted solely in relation to the advancement of the tongue since it is also affected by tongue height and lip rounding, which represent different forms of vocal tract constriction.

Another factor that may account for some of the unpredicted correlations between acoustics and kinematics in the present study is the anatomic variability in individuals' vocal tract structures. As Kent et al. (1999) noted, since formants depend in part on the length of the vocal tact, an individual speaker's anatomic characteristics should be considered. The size and shape of the articulators, such as tongue, palate, pharynx, lips, jaw, and teeth can vary across individuals. If an individual has a larger tongue, its range of motion may not be equivalent to that of another individual with smaller structures. Additionally, the movement of vocal tract structures other than in the oral cavity may have influenced the formant frequencies. For example, raising the larynx or constricting the pharynx would be expected to raise formant frequencies. These movements would not be reflected in the position of the magnet attached to the tongue, and thus may have influenced the kinematic/acoustic correlations in the present study.

Individuals' idiosyncratic articulatory patterns could also have influenced the acoustic-kinematic associations in the present study. The ability of the vocal tract to achieve an equivalent acoustic output from slightly different articulatory movements – motor equivalence – could have contributed to the present findings (Hughes & Abbs, 1976). Even if individuals do not move a given articulator the same way to produce a certain sound, other vocal tract adjustments can compensate to produce the target sound accurately. Thus, in this study it is possible that the tongue movements could have varied across speakers even though the acoustic output was similar.

One factor which may have influenced the acoustic-kinematic correlations is coarticulation. Since the four target diphthongs were segmented out of the words in sentences, it is possible that the lingual movements were influenced by the production of the adjacent sounds. It has been well established that coarticulatory influences can cause the production of a target sound to change (e.g., Beddor, 2009; Ohala, 1993; Story, 2009). Thus, the diphthongs produced in the present study may have been produced differently than in isolation.

Limitations and Suggestions for Further Research

One of the limitations of the current study lay in the process of operationally defining the on-glide, transition, and off-glide of each diphthong. In order to avoid the influence of subjective segmentation judgments during data analysis, the audio recording was automatically divided into 8 equally-spaced segments. The first two were defined as the diphthong on-glide or initial steady-state. The next four segments were defined as the transition, during which a large tongue movement would be anticipated as it moves from the first vowel to the second vowel of the diphthong. The last two segments were defined as the off-glide or final steady-state. This operational definition of the three parts of the diphthong may have been overly simplistic, in that formant track movements often occurred during the defined steady-states.

However, the automatic segmentation was a necessary process for this study because reliably identifiable segments were required in order to quantify and compare the two physically different signals from the kinematic and acoustic sources. The researcher initially anticipated a stronger correlation during the transition than the steady-states due to the prediction of a relatively larger tongue movement. The results of the analysis, however, revealed evidence of formant changes throughout the duration of the diphthong for many sounds (see Figures 1 and 2).

The participants in this study were individuals with MS and age-matched healthy controls. However, it was not the goal of the study to directly compare speakers with MS and controls. Instead, this dataset from a larger study was a convenient sample to allow the researcher to examine the linkages between acoustics and kinematics. Future studies might profitably examine whether the acoustic/kinematic correlations are different between normal and dysarthric speech.

Conclusion

It is generally accepted that changes in the formant frequencies of vowels and diphthongs indirectly reflect tongue movements; F1 reflects vertical displacement and F2 primarily reflects anteroposterior movement. Accordingly, the present study was performed to test the strength and consistency of this association. The results of the current study showed that the formants were not consistently predictive of tongue movements; in other words, there was variability across individuals and sounds in the strength of the correlations between the acoustic and kinematic variables. These findings suggest that the assumption about the relationship between the formants and tongue movements may be too simplistic and in reality their relationship appears to be far more complex. Therefore, researchers should be cautious when using only acoustic measures and aware that they might not always accurately reflect physical movements of articulators.

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Appendix A

Initial Letter

Dear (Name of Patient),

Three graduate students and their supervising faculty at Brigham Young University (BYU) are conducting a study to examine the effects of fatigue on the speech and language of individuals with MS. They would like to meet with people whose communication has been affected, and who experience fatigue as a symptom of MS. Participation would involve volunteering 2 hours of time during the month of November for an analysis of speech and language characteristics. If you decide to take part in this study, you will need to go to the BYU Speech and Language Clinic, receive a free hearing evaluation, read some simple passages of text into a microphone, and have a short interview with the researchers.

As you know, MS affects every person differently. The purpose of this study is to better understand how both MS and fatigue affect communication. If you would be willing to participate in this study, please complete the enclosed response card and return it in the stamped, pre-addressed envelope or call one of the following numbers:

Kristi Hollis: (801) 123-4567 Kate King: (208) 123-4567

In the event that no one is available to take your call, please leave a message including your full name and contact information. Because your medical information is confidential, the BYU researchers do not have your name or contact information. If you choose not to send in the response card or call them, your privacy will be maintained, and nobody will call you in connection with this study.

Thank you,

Dr. Pamela Vincent and Staff

Appendix B

Telephone Interview Questions

Upon receipt of the response card, each participant was telephoned for an initial screening. The purpose of the screening was to group participants and to ensure that the participants: 1) were at least one year post-diagnosis; 2) considered fatigue as a symptom of their MS; 3) were native English-speakers; 4) considered their vision and hearing normal, and 5) had no history of speech or language problems prior to the onset of MS.

1. When were you diagnosed with MS?
2. What are the primary symptoms that you experience with MS?
3. Is fatigue one of the symptoms that you associate with your diagnosis of MS?
4. If yes, how often do you feel fatigued? Daily, Once a week, Several times a week, Depends
5. If yes, are there any activities that trigger the fatigue?
6. Before being diagnosed with MS, have you ever had any speech or language problems? If so, what?
7. Have you noticed any changes, even subtle changes, in the way that you communicate since you have been diagnosed with MS?
8. Would you consider your hearing to be normal?
9. Do you wear hearing aids?
10. Would you consider your vision to be normal?
11. Do you wear glasses or contacts?
12. Is English your native language?
13. To participate in the study we would ask you to come to BYU campus and have your speech recorded twice on the same day. These recordings would each take

about 1 hour and would be approximately 6 hours apart. Would you be able to travel twice to BYU campus for these recordings?

14. What day of the week would be most convenient for you to come to BYU campus?
15. We will contact you to make an appointment and then again as a reminder of your appointment. In the event that you are unavailable to answer your phone, do we have your permission to leave a detailed message, or would you prefer that we just leave a call-back number?

Appendix C

Informed Consent

Introduction

You have been invited to participate in a research study about the effect fatigue has on the speech and language of persons with MS. This study is being conducted by Kristi Hollis, Kate King, and Gwi-Ok Jang, graduate students at Brigham Young University, under the direction of Dr. Christopher Dromey and Dr. Ron Channell, who are members of the faculty in the Communication Disorders Department. You have been invited to participate because you have MS, and have no history of a previous speech or language disorder.

Procedures

You will be asked to attend two recording sessions lasting approximately one hour each; one during the morning and one in the late afternoon of the same day. Before the recording you will receive a complimentary hearing evaluation, and be asked to fill out a short questionnaire that will be used to develop a demographic profile of the participants of this study. You will then be asked to rate your current level of fatigue.

Next you will participate in a short interview with one of the researchers. This interview will be recorded and used as data for the research study. Then, while sitting in a sound booth in 106 TLRB, you be asked to read a number of sentences and paragraphs. You will then be asked to repeat these samples while wearing a device that measures tongue position in the mouth. The device includes a small magnet that is attached to your tongue with a drop of removable adhesive. You will wear a headset that tracks the position of the magnet within your mouth. You will be asked to return later the same day to repeat the recordings. These recordings will be analyzed with a computer program.

Risks/Discomforts

There are no known risks associated with participation in this study. The equipment used in this study has been used previously here and elsewhere with no adverse effects.

Benefits

Aside from a complimentary hearing evaluation, you will receive no direct benefits from participating in this study. However, the results of this study are expected to provide valuable information about how fatigue affects communication in persons with MS.

Confidentiality

An anonymous identification number will be used in storing and analyzing the recordings of each speaker. Your name and other identifying information will not be used in print or electronic records of this study. Only summary data without reference to names will be reported when the study is complete.

Participation

Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without any impact on your medical treatment or your relationship with BYU.

Questions about the Research

If you have any questions about this study, you may contact Dr. Christopher Dromey at (801) 422-6461.

Questions about Your Rights as a Research Participant

If you have questions you do not feel comfortable asking the researcher, you may contact Sandee Muñoz, IRB Administrator, at (801) 422-1461.

Signatures

I understand what is involved in participating in this research study. My questions have been answered and I have been offered a copy of this form for my records. I understand that I may withdraw from participating at any time. I agree to participate in this study.

____ ________________________

Signature Date

____

Printed Name