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The Effect of Fatigue on Acoustic Measures of Diphthongs in Individuals with Multiple Sclerosis

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THE EFFECT OF FATIGUE ON ACOUSTIC MEASURES OF DIPHTHONGS IN INDIVIDUALS WITH MULTIPLE SCLEROSIS

by

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ABSTRACT

THE EFFECT OF FATIGUE ON ACOUSTIC MEASURES OF DIPHTHONGS IN INDIVIDUALS WITH MULTIPLE SCLEROSIS

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Although recent literature suggests that fatigue influences the communication of people with multiple sclerosis (MS), its relationship to acoustic measures of speech, specifically formant transitions during diphthongs, has not been explored. In the present study, 11 participants diagnosed with MS, two of whom were perceptually dysarthric, and 12 control subjects were recorded as they performed selected speech tasks in both the morning and the afternoon. Before each recording session, participants rated their fatigue level. The participants with MS gave significantly higher ratings of fatigue than the control group. The speakers with MS had longer diphthong durations in a non-fatigued state, but not in a fatigued state, which was indicative of the variability in this group of speakers. Fatigue was not shown to affect any other acoustic variables. This finding may be attributable to the mildness of the speech impairment of this sample of speakers with MS.

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Introduction

Neurodegenerative diseases such as Parkinson's disease (PD), Alzheimer's disease, and multiple sclerosis (MS) can change many aspects of a person's life. These changes may include speech and language deficits that impact an individual's ability to communicate. A small proportion of people with Parkinson's disease and Alzheimer's disease seek services from speech-language pathologists to help manage their communication challenges, but an even smaller fraction of individuals with MS seek such treatment (Yorkston et al., 2003). Individuals with MS who have communication deficits may benefit from speech and language services, but their needs must be better understood in order to provide effective care.

One of the barriers to understanding these communication deficits is the variability in the manifestation of the disease. Disease progression and symptoms vary from person to person, making generalization difficult, and research in the area of communication disorders of people with MS is limited. However, many aspects of the dysarthria that occurs with MS have been identified by examining both a variety of perceptual characteristics and acoustic measures (Darley, Brown, & Goldstein, 1972; Fitz Gerald, Murdoch, & Chenery, 1987; Hartelius, Nord, & Buder, 1995; Theodoros, Murdoch, & Ward, 2000). Other investigators have identified the characteristics of fatigue in MS, and how it affects functional living (Freal, Kraft, & Coryell, 1984; Yorkston, Klasner, & Swanson, 2001). Fatigue has been identified as a major contributor to communication changes in individuals with MS, particularly in relation to language and attitudes about communication (Yorkston et al., 2001), but its impact on speech disorders has not been documented. Previous studies found the prevalence of dysarthria in MS to range between 23-50% (Darley et al., 1972; Fitz Gerald et al., 1987; Hartelius et al., 1995; Theodoros et al., 2000), while Freal et al. (1984) found that fatigue is a major symptom for 78% of individuals with MS. Since the majority of people with MS experience fatigue, it is reasonable to expect that many of those who experience dysarthria would also experience fatigue. Because fatigue is traditionally associated with muscles and the motor system, increasing knowledge of how it interacts with dysarthria, a motor speech disorder, is important to understanding the speech deviations associated with MS. The purpose of this study is to examine specific acoustic measures that characterize dysarthria in individuals with MS and how these measures are affected by fatigue.

Review of Literature

The pages that follow will summarize the research literature that describes the characteristics of MS as well as the typical patterns of disordered communication associated with this disease. Fatigue in MS, and its potential impact on speech, will also be considered.

Nature of MS

There are currently approximately 400,000 Americans with a diagnosis of MS, and there may be as many as 2.5 million cases of MS worldwide (National Multiple Sclerosis Society, 2006). Multiple sclerosis affects the central nervous system (CNS) by attacking the myelin sheath that surrounds the nerve fibers, leaving behind scar tissue that is known as plaque, lesions, or sclerosis. Because the myelin sheath helps conduct nerve impulses along the nerve fiber, when the sheath is destroyed or damaged, the nerve is no longer able to effectively carry signals. The cause of MS is unknown, but it is considered an autoimmune disorder. Symptoms of MS are varied because lesions can occur in almost any part of the

CNS. The most common symptoms include, fatigue, vertigo, numbness, gait instability, cognitive issues, and dysarthria (National MS Society, 2006).

General characteristics. MS is usually divided into subtypes based on the characteristic pattern of the disease. These types are relapsing-remitting, secondary progressive, primary-progressive and progressive-relapsing. Relapsing-remitting is the most common type of MS (National MS Society, 2006), and in the typical relapsing-remitting pattern, the individual experiences episodes where neurological function worsens and symptoms increase. These episodes or exacerbations are followed by periods of partial or complete recovery (remissions). During the remission, the disease does not progress. Of those initially diagnosed with relapsing-remitting MS, many eventually begin to follow the secondary-progressive pattern (National MS Society, 2006). If the disease is following the secondary-progressive pattern, the patient presents with relapsing-remitting MS, but it is followed by a steadily declining state. Primary-progressive MS is a relatively rare pattern (National MS Society, 2006) where the disease slowly, but continuously worsens from the onset. There are no periods of remission, but the rate of decline may vary and include temporary plateaus and minor improvements; however, the overall pattern is one of steady decline. The last pattern of MS is progressive-relapsing. This form of MS is also relatively rare (National MS Society, 2006). People with this subtype of the disease experience a steady worsening from the onset, but there are periods of remission. It differs from the relapsing-remitting pattern because the disease continues to worsen between the remission periods.

Characteristics of dysarthria in MS. Acoustic analysis has been widely used to describe characteristics of both normal and disordered speech. The advantage of acoustic measurements is that they provide a way to quantify characteristics of speech beyond a listener's perceptual impressions and objectively document the degeneration of motor speech function as the disease progresses. A relevant clinical benefit is that acoustic measurements may help document the effects of treatment and may be used to identify subclinical manifestations of MS and thus help in differential diagnosis of the disease (Hartelius, 2000). Because dysarthria is a motor speech disorder, there are difficulties with making inferences from the acoustic properties of speech to the mechanism that is producing them (Hartelius et al., 1995). However, disordered movements can change the acoustic properties of speech, which in turn can affect its intelligibility.

The severity of dysarthria in MS varies with each individual and seems to be related to the pattern of the disease, rather than a site of lesion or the length of time the person has had the disease. Yorkston et al. (2003) surveyed 739 individuals with MS to better understand the correlation between speech problems and the severity of MS. These authors noted that "a strong relationship exists between the severity of MS and the severity of speech problems" (p. 79). These findings were similar to those of Hartelius, Runmarker, and Anderson (2000), who studied the prevalence and characteristics of dysarthria in MS and found that in the majority of MS cases presenting with dysarthria, the impairment was considered mild or moderate. The severity of speech deviation was not necessarily associated with a particular site of lesion, but it correlated with the severity of neurological involvement. Hartelius, Runmarker, and Anderson recognized that dysarthria severity was also linked to whether or not the person "had entered a progressive stage of the disease and for how long that progressive stage had lasted" (p. 175). This study is consistent with earlier findings by Darley et al. (1972) that "severity of dysarthria in multiple sclerosis is not related to age of patient or duration of illness but is positively related to the severity of neurologic involvement. Most speech deviations become more prominent as additional motor systems become involved" (p. 245). Severe dysarthria that can be perceived by the listener is most apt to occur in individuals who are in one of the progressive patterns of MS; however, non-dysarthric speakers with MS may manifest some early features of dysarthria on a subclinical level when acoustic analysis is used to examine speech.

There is not a unique type of dysarthria associated with MS; however, dysarthria in MS is usually described as mixed spastic-ataxic. Darley et al. (1972) studied 168 patients in various stages of MS over 38 months. The most prominent speech deviations that Darley et al. noted were harshness, impairments to articulation and to the control of loudness and pitch, and the inability to use the voice for emphasis. In a later study, Fitz Gerald et al. (1987) studied 23 individuals who were considered to have severe MS. These authors found speech deviations in articulation, phonation, respiration, resonance, and prosody. These deviations included deficits in respiratory support for speech in all of the individuals in the study. There were also deficits in pitch variation and steadiness, abnormal prolongation of intervals, and a harsh voice quality in 91% of the individuals in the study. In the earlier study by Darley et al., respiratory problems were not viewed as significant, but it is possible that this difference was due to the individuals' severity of MS.

Objective Measures of Dysarthric Speech

Acoustic measures of speech in MS have been used to identify the characteristics of dysarthria, including deficits in prosody, phonation, and articulation. Hartelius et al. (1995) used acoustic analysis to describe the speech of five individuals with MS compared to two healthy controls. These authors identified three acoustic characteristics that differentiated the speakers with MS from the controls, suggesting that these acoustic indexes should be included in future studies. The acoustic measures included the “patterns of relative timing, or the scanning aspect of the MS speech,” as well as “spectrum analysis of fundamental frequency in sustained phonation” and “articulatory deficits” (p.118).

Acoustic measures of prosody. Dysarthric speech is usually slower than normal speech. This and other temporal differences can affect intelligibility. Because of the ataxic element in their speech, dysarthric speakers with MS frequently have prosodic difficulties, such as abnormal loudness, impaired pitch control, and scanning speech (Duffy, 2005). Scanning speech was one of the original triad of symptoms that J. M. Charcot identified in 1877 when he classified MS, and he described scanning speech as follows:

> The affected person speaks in a slow, drawling manner, and sometimes almost unintelligibly. It seems as if the tongue had become ‘too thick’ and the delivery recalls that of an individual suffering from incipient intoxication (qtd. in Darley et al., 1972, p. 231).

Scanning speech or impaired emphasis refers to both the slowness of speech and the inappropriate emphasis on both the stressed and unstressed syllables. Acoustic measures of the overall speech rate and average variations in frequency and amplitude have been used to better define the perceptual characteristic of scanning speech or impaired emphasis (Hartelius et al., 1995).

Hartelius et al. (1995) examined the temporal speech characteristics of five dysarthric speakers with MS, measuring the overall speech time and pause time during a text reading task. Compared to control speakers, three of the individuals with dysarthria had a slower speaking rate and more frequent pauses. Hartelius et al. also measured the durations of both high and low vowels and found that the values for speakers with MS and normal speakers were similar. However, when these researchers examined the syllable timing patterns for CVCVC words, they found that the 3 speakers with MS who had a slower than normal speaking rate also had a tendency to equalize syllable durations, which is an acoustic manifestation of impaired emphasis.

Hartelius, Runmarker, Andersen, and Nord (2000) examined the patterns of relative timing in the speech of both English and Swedish speakers with MS. These researchers investigated syllable duration and its variability as well as the spacing between syllabic nuclei, or the inter-stress interval. They compared individuals with ataxic dysarthria, MS and dysarthria, and a control group. English and Swedish are classified as stress-timed languages, and the durations of syllables in speech are more variable, while the durations of the inter-stress intervals are more isochronous. Thus, even though the syllables vary, there is a predictable stress pattern to speech. Hartelius et al. found that the group with MS showed increased syllable durations and decreased variability in syllable durations when compared to a control group, and significantly longer and more variable inter-stress durations—an acoustic measure of the perceptual characteristic of scanning speech. These researchers concluded, “temporal dysregulation is indeed a primary characteristic of ataxic dysarthria in MS” (p. 277). This was consistent with earlier findings by both Fitz Gerald et al. (1987) and Hartelius et al. (1995) indicating that the majority of individuals with dysarthria associated with MS did not have a normal stress pattern during speech.

Diadochokinesis (DDK) can be used as a measure of syllable timing and rhythm in speech (Kent, Weismer, Kent, Vorperian, & Duffy, 1999). Irregular syllable timing during DDK is strongly associated with ataxic dysarthria and can be associated with spastic dysarthria as well (Tjaden & Watling, 2003). DDK measures are divided into two types:

alternating motion rate (AMR) and sequential motion rate (SMR). AMR is measured as the rapid repetition of a single syllable (/pʌ/), and SMR is measured as the rapid repetition of a sequence of syllables (/pʌtʌkʌ/). Tjaden and Watling measured DDK for individuals with MS and PD as well as a matched control group. These researchers found several characteristics that differentiated the group with MS from both the group with PD and the control group. Compared to both people with PD and the control speakers, people with MS had an overall slower DDK rate (for both the AMR and SMR). Speakers with MS also had longer syllable durations in the AMR, but not the SMR task, and longer gap durations between syllables for the AMR.

Fundamental frequency instability. Fundamental frequency (F_0) reflects the rate of vocal fold vibration and closely matches our perception of pitch (Ferrand, 2007). In speech, changes in F_0 can reflect linguistic and affective prosody; if a person does not change their fundamental frequency adequately, this disturbs the prosody of speech and may contribute to the perception of a speech disorder. Additionally, measuring the F_0 of vowels can reveal two types of subtle phonatory instability: perturbation and modulation. This latter form of phonatory instability, also known as vocal tremor, has been identified as a possible characteristic of the speech disorder in individuals with MS (Hartelius et al., 1997).

A perceptual evaluation of dysarthric speech in individuals with MS (Fitz Gerald et al., 1987) found that 91% exhibited either mild to moderate monopitch or tremulous pitch. A recent study of the perceptual characteristics of dysarthria in Swedish and Australian speakers with MS also found abnormally increased and decreased pitch levels and reduced pitch variation in the Australian speakers, as well as both increased and decreased pitch levels in the Swedish speakers (Hartelius, Theodoros, Cahill, & Lillvik, 2003). However, when Hartelius et al. (1995) analyzed recordings of five individuals with MS and two control speakers for their F_0 and the F_0 range during a text reading task, these researchers found that neither F_0 nor F_0 range distinguished the speakers with MS from the controls. In a more recent study (Feijo et al., 2004), F_0 and standard deviation of F_0 were extracted from a recording of the prolonged vowel /ɑ/ from 30 individuals with MS and a control group. The individuals with MS had both a higher mean F_0 and standard deviation of F_0 when compared to the control group.

While investigating the F_0 of the five speakers with MS, Hartelius et al. (1995) performed a spectral analysis of the sustained Swedish vowels /i/, /e/, /æ/, and /ɑ/. This showed that the phonatory instabilities of people with MS were greater in both amplitude and frequency than those produced by speakers in the control group. Hartelius, Buder, and Strand (1997) followed this pilot study with research into long-term phonatory instability. These researchers used the classifications of wow (1-2 Hz oscillation), tremor (2-10 Hz oscillation), and flutter (10-20 Hz oscillation) to determine if speakers with MS had different patterns of long-term phonatory instability than speakers without MS. The samples were analyzed for both amplitude and frequency modulation, and these authors found that speakers with MS could be differentiated from the control group because both amplitude and frequency of phonatory instability differed significantly. However, findings from a study conducted by Feijo et al. (2004) revealed that both the magnitude and frequency of phonatory instability of speakers with MS were within the normal range. Feijo et al. asserted that this difference could be accounted for by differences in instrumentation. In the same study, Feijo et al. used wide- and narrow-band spectrographic analysis to detect the presence of dysphonic symptoms and found that individuals with MS were 2.2 times more likely to have dysphonic symptoms than the age and gender-matched controls.

Acoustic measures of articulation. Imprecise articulation is a common perceptual characterization of dysarthric speech (Duffy, 2005). Unfortunately, measuring imprecise articulation is challenging because each phoneme has distinct perceptual, physiologic, and acoustic properties (Kent & Kim, 2003). No single acoustic measure is adequate to measure imprecise articulation. The research into acoustic patterns of imprecise articulation in MS is scarce. Because consonants differ in voicing, place of constriction, and manner, quantifying imprecise consonants is especially difficult. Fitz Gerald et al. (1987) observed imprecise consonant production in 83% of their sample of people with MS, reporting that this feature was the most common articulation deficit. In a study of five speakers with MS who were dysarthric, Hartelius et al. (1995) described some of the features of consonant imprecision that were evident in the acoustic signal of the different speakers. Not all speakers presented with the same acoustic features, but the features noted included inadequate closure of stops, spirantization, continuous voicing, nasal formants during voiced stops, and voice onset imprecision.

Formant frequencies are determined by the shape and size of the resonating cavities formed by constrictions in the vocal tract. Each vowel is characterized by a different formant pattern, and as the tongue position changes in the oral cavity, the formant frequencies change and a distinct vowel is perceived (Ferrand, 2007). The first (F1) and second (F2) formant frequencies can be plotted on an F1/F2 graph to show the acoustic vowel space. Reduced tongue movement is associated with a contraction of the vowel quadrilateral, and compression of the vowel space is a general property of dysarthria that has been related in some studies to intelligibility (Kent & Kim, 2003). Tjaden and Watling (2003) examined the vowel space of 15 people with MS who had mild to moderate dysarthria. These researchers found that asking the person to speak slowly increased the vowel space for 11 of the 15 speakers, while asking the speaker to speak loudly increased the vowel space of 4 of the 15 speakers.

Changes in F2 that accompany articulatory movements are represented by the F2 slope, which primarily reflects tongue position changes (Kent et al., 1999). F2 slope has been associated in some cases with intelligibility in dysarthria (Rosen, Goozee, & Murdoch, 2008). Hartelius (2000) reported that in the speech of a sample of people with MS and dysarthria, F2 transitions were generally slower and more shallow than for people without dysarthria. Tjaden and Wilding (2004) also found that F2 slope tended to be more shallow for speakers with MS than it was for controls. More recently, Rosen et al. (2008) compared F2 movement and F2 slope range in 12 speakers with MS who exhibited mild dysarthria against a control group of 16 normal speakers. The data were gathered from recordings of the Grandfather Passage that were divided into utterances to be analyzed. The utterances were divided into two sets: one that included large F2 movements, and one that included smaller, more typical F2 movements. The groupings were used to determine whether some types of phonetic structures would be better suited to measuring changes in F2. The results indicated that dysarthria secondary to MS is more readily detectable where there are rapid changes in F2, and that some phonetic environments, such as diphthongs, liquids and glides, were better suited to revealing these deficits. This study also measured F2 range, which is the difference between the highest and lowest observed F2 instantaneous slope values, and concluded that there was no significant difference in F2 slope range for speakers with MS as compared to matched controls. This suggested to the authors that speakers with MS could produce vocal tract movements that were similar in extent to those of healthy speakers.

Physiologic measures of tongue movement. Disordered tongue movement and imprecise consonants have been described as characteristic of dysarthria in MS (Darley et al., 1972; Fitz Gerald et al., 1987; Hartelius et al., 1995), but there has been relatively little research to examine the exact nature of the disordered movement. Although good lingual function—including strength, placement, and range of motion—is necessary for precise articulation of consonants in speech, there have been limited studies to examine these characteristics. Studies that have examined the relationship between tongue strength and speech intelligibility have not revealed a strong correlation (Neel, Palmer, Sprouls, & Morrison, 2006; Robin, Goel, Somodi, & Suschei, 1992). It is implicitly understood that disordered tongue movement underlies imprecise consonants and contributes to poor intelligibility, but more research is needed to examine the specific physiologic characteristics of imprecise consonants. Murdoch, Spencer, Theodoros, and Thompson (1998) studied the contribution of tongue strength and lip pressure to intelligibility in speakers with MS. These researchers found that there was no difference between lip function for speakers with MS and matched controls, but there were significant differences in tongue function. Murdoch et al. measured maximum tongue pressure, fine tongue pressure, repetition of maximum tongue pressure, fast rate maximum tongue pressure, and sustained submaximal tongue pressure. No significant differences in fine tongue pressure between speakers with MS and a control group were found, but all other measurements showed a significant difference. Murdoch et al. then compared the tongue control measures between speakers with MS and dysarthria and speakers with MS without dysarthria. These researchers found that both dysarthric and nondysarthric speakers with MS had significantly reduced maximum pressure, fewer repetitions, and decreased endurance compared with the control group. While it was suggested that impaired tongue function was an underlying cause of imprecise consonants, no clear correlation between these non-speech measures and speech intelligibility was detected.

In a more recent case study Murdoch, Gardiner, and Theodoros (2000) used electropalatography to examine tongue placement and timing during the articulation of consonants for a speaker with MS and a moderate ataxic dysarthria. This case study examined the tongue placement for /l/, /n/, /s/, /z/, /d/, and /t/. In general the tongue placement of the speaker with MS was similar to the tongue placement of four control speakers, although the speaker with MS did overshoot some of the articulatory patterns as would be expected with an ataxic dysarthria. Murdoch et al. found a greater deviation in temporal measurements. The speaker with MS made timing errors, in the form of closure duration, when compared to the control speakers. When producing the alveolar stop /t/, the speaker had longer closure duration, but the speaker's constriction duration during the fricative /s/ was shorter than for the control group. This suggests that timing rather than placement or strength may contribute to intelligibility changes in MS. However, this was a case study, and a larger scale investigation is needed to confirm these findings.

Hartelius and Lillvik (2003) investigated lip and tongue function as it relates to dysarthria in MS from a perceptual viewpoint by administering a clinical dysarthria test. These researchers confirmed the earlier findings of Murdoch et al. (1998) that tongue function was more impaired than lip function for both dysarthric and nondysarthric speakers with MS. Hartelius and Lillvik further noted that deficits in tongue function were associated with the development of general disease symptoms and may be a useful indicator of disease progression.

Impact of Fatigue on Performance

Fatigue in MS is a common symptom, but further investigation is needed to better understand how it is experienced by individuals with the disease. Fatigue is a slowing of muscle action or a decrement in performance that can be divided into a peripheral component, which affects the activation of muscles, and a central component that affects cognitive abilities and the activation of the peripheral nervous system (PNS) by the CNS. Whether the fatigue experienced by people with MS has a greater peripheral component or a greater cognitive component is not known, although a study measuring fatigue in the leg muscles of individuals with MS concluded that the excessive fatigue may be explained by impaired excitation and abnormal metabolism (Sharma, Kent-Braun, Mynhier, Weiner, & Miller, 1995).

Activities of daily living. Regardless of the underlying cause, for many people with MS, fatigue affects all other aspects of their lives. Freal et al. (1984) surveyed 656 individuals with MS, and 78% of the respondents identified fatigue as a symptom. In a follow-up questionnaire respondents were asked to further describe their experience of fatigue. Of the 309 respondents, 71% described it as a feeling of “weakness, tiredness and/or the need to rest;” 69% indicated that it happened daily; and 48% described, “a worsening of MS symptoms not otherwise experienced” (p. 136). Stuifbergen and Rogers (1997) conducted interviews with 13 individuals with MS to better understand the occurrence of fatigue. These authors found that for many people with MS, fatigue is always present and impacts all aspects of the individual’s life. Yorkston et al., (2001) used ethnographic interviewing techniques to assess the communication difficulties associated with MS for seven individuals. These respondents identified fatigue as a major contributor to communication changes, in both their speech and language, since the diagnosis of their disease. These studies suggest that fatigue affects the individual with MS in many aspects of communication, but have not specifically identified how speech is affected.

Speech. There is little research detailing the influences of fatigue on acoustic measures of normal or disordered speech. A study by Solomon (2000) examined the effects of lingual fatigue on the speech of normal speakers. After lingual fatigue was induced in eight normal speakers using the Iowa Oral Performance Instrument (IOPI), perceptual and acoustic measures, including spectral moments, voice onset times, formants and formant transitions, and temporal measures were taken in a fatigued and nonfatigued state. Solomon demonstrated that lingual fatigue can be induced with excessive exercise, and speech perceptually deteriorates with induced lingual fatigue. Some of the acoustic measures, including the first and third spectral moments for alveolar consonants and possibly vowels and diphthongs, reflected the perceptual changes in normal speakers. In a later study, Solomon and Makashay examined orofacial fatigue and speech precision in individuals with PD (as cited in Solomon, 2006). A fixed-time speech task (repeating strings of syllables for 60 minutes) was used to simulate speech-induced fatigue. These researchers demonstrated that people with PD had reduced tongue endurance, but there was no significant association between reduced tongue endurance and speech precision, suggesting that the articulation system of individuals with PD is robust and fatigue- resistant. While fatigue commonly occurs in individuals with PD, it is not considered a primary symptom as it is in other neurological disorders such as MS. The effect of fatigue on the speech of individuals with these neurological disorders has not been investigated.

Although MS is a variable disease with different characteristics and patterns of progression across individuals, fatigue can aggravate symptoms and affect the person's motivation. A better understanding of how fatigue interacts with speech could help clinicians to identify the challenges that people with MS face and how speech treatments might need to be modified. The purpose of the current study was to investigate the effects of fatigue on the speech of individuals with MS by examining acoustic measurements in a fatigued and nonfatigued state. Because previous studies have shown phonatory instability, fundamental frequency, formant slope, and tongue movement differences to be characteristic of dysarthria in speakers with MS, speech tasks that would be sensitive to these characteristics were included in the recordings. However, the present study will focus on the effect of fatigue on the formant slopes and transitions during diphthongs. Other speech data collected during this investigation may be examined in future studies.

Method

The current study was part of a larger research effort. In addition to the speech production variables discussed below, language samples were collected on the same day from these participants and used in other research projects, which are not included in the present report.

Participants

Participants in this study were 11 individuals who were diagnosed with MS by a practicing neurologist specializing in the disease. To protect patient privacy and to comply with HIPAA regulations, the initial contact with the patients was made by the neurologist's office. Each potential participant was sent a letter describing the study and asked to reply if he or she was interested. The full text of the letter appears in Appendix A. Individuals who expressed interest in participating in the study were then contacted by telephone, and an initial screening interview was conducted. The questions posed to potential participants are listed in Appendix B.

All the participants in this study had been diagnosed for at least one year; considered fatigue as a primary symptom of their MS, had no history of speech or language problems prior to the onset of MS, and were native speakers of English. Although six of the individuals who participated indicated during the telephone interview that they experienced speech anomalies similar to dysarthria during MS exacerbations, these speech impairments were not apparent in connected speech during the recording sessions for this study. A perceptual judgment of the recordings by two listeners found that most speech of the speakers with MS was within normal limits, with one speaker being judged to have a moderate dysarthria and another to have a mild dysarthria. All participation was voluntary, and the sample included individuals with both the relapsing-remitting and the secondary-progressive patterns of MS. Demographic details are provided in Table 1. Control data were gathered from a group of individuals without MS who were matched for gender and age. Each participant was informed of the purpose of the study and given the opportunity to ask questions of the researchers. After all their questions were answered, they signed an informed consent document approved by the University IRB (see Appendix C).

Instrumentation

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

Table 1

Demographic Characteristics of the Participants with MS

Speaker	Age (years)	Gender	Years Since Diagnosis	Pattern of MS[a]	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

[a]Patterns of MS are identified as follows: RR = relapsing-remitting; SP = secondary-progressive.

signal passed through a Samson Mix Pad 4 preamplifier and then a Frequency Devices 9002 low pass filter set at 12 kHz. A 16 bit Windaq 720 interface was used to digitize the acoustic signal from the microphone at 25 kHz, and the voltage output of a sound level meter (Larson Davis 712) was used to record speech intensity. To measure tongue movement, an adapted BioResearch Associates JT-3 jaw tracking instrument was used, as described by Dromey, Nissen, Nohr, and Fletcher (2006). The sound level meter and tongue movement signals were digitized at 1 kHz.

Procedure

Previous research has shown that most individuals with MS report that disease-related fatigue occurs more frequently in the afternoon (Morris, Cantwell, Vowels, & Dodd, 2002; Yorkston et al., 2003). Therefore, data were collected at two different times of day. The participants were recorded in the morning, when they were more likely to be well rested, and in the early afternoon, after a typical day’s activities, when they were more likely to be fatigued. To counterbalance for potential practice effects, half of the participants made their first recording in the morning and the second recording in the afternoon of the same day, and half made their first recording in the afternoon and the second recording in the morning of the next day. Before each recording session, they were asked to rate their current level of fatigue on a 4-point scale (1 = not fatigued, 2 = mildly fatigued, 3 = moderately fatigued, and 4 = severely fatigued) and to answer a short survey describing aspects of their fatigue. The complete fatigue survey can be found in Appendix D. As noted above, a 20-minute language sample that was used for a separate research project was collected during the same recording session. To counterbalance any effects of fatigue, half of the participants recorded the language sample before the speech recording, and half recorded the language sample after the speech recording. Prior to the speech tasks, a small magnet was attached to the participant's tongue to track its movement as described by Dromey et al. (2006). The participant then completed the speech tasks in an Acoustic Systems sound booth. The same procedure was followed during the second session.

Speech Tasks

Each participant was asked to complete four speech tasks: maximum sustained vowel phonation, diadochokinesis (DDK), sentence repetition, and a connected speech sample. The researcher demonstrated the maximum phonation task and then instructed the participant to take a deep breath and say /ɑ/ at a comfortable loudness level and pitch for as long they could; this was repeated three times. The DDK included both the alternating motion rate (AMR) task of repeating the syllables /pʌ/, /tʌ/, and /kʌ/ and the sequential motion rate (SMR) task of repeating /pʌtʌkʌ/. The researcher demonstrated each task and then instructed the participant to repeat the syllable as quickly and smoothly as possible in one breath. For the final two tasks the participant was asked to repeat the sentences *The boot on top is packed to keep* and *The boy gave a shout at the sight of the cake* five times in a normal speaking voice and to read a portion the Rainbow Passage (Fairbanks, 1960) in their normal reading voice.

Data Analyses

To determine the effect of fatigue on the rate and extent of tongue movement in speech, the diphthongs /aɪ/, /aʊ/, and /ɔɪ/ were segmented and frequency tracks for the first and second formants of the diphthongs were extracted from the five repetitions of the sentence *The boy gave a shout at the sight of the cake* using PRAAT acoustic software (version 5.0.47; Boersma & Weenink, 2007). The formant traces were extracted to a text file and then imported into Matlab (The Mathworks, 2005). A custom Matlab algorithm was used to determine formant values for the vocalic segments at 5ms intervals. Using values from the extracted formant tracks, average F1 and F2 frequencies were calculated at eight different equidistant measurement points throughout each diphthong's overall duration (t1–t8). Thus, t1 was an average of the formant values in the initial 12.5% of the diphthong's duration, t2 was an average of the formant values in the second 12.5% of the diphthong's duration, and so on. Onset and offset values for the diphthongs were calculated at 25% (t2–t3) and 75% (t6–t7), respectively, thus limiting the influence of the adjacent consonants. The transition slope of the diphthongs was defined as the frequency difference between the onset and offset values as a function of time.

A fatigue rating was determined from the participant's answers to the fatigue survey. The answer for each question on the fatigue survey was given a score from 1 to 4 depending on whether the participant strongly disagreed, disagreed, agreed, or strongly agreed with the statement. These answers were added together to compute a fatigue score for the individual. This score was averaged with the individual's reported fatigue rating to give each individual an overall fatigue rating for each recording session.

Statistical Analyses

This study had two main purposes. The first was to determine if the diphthong formant transitions of the speakers with MS could be differentiated from those of a control group. The second goal was to determine if fatigue in MS influenced these acoustic measures. To test the first hypothesis, one-way analyses of variance (ANOVA) using SPSS 16 were run on the diphthong duration, formant transitions, and formant slopes of the MS group versus the control group. Then, to determine if there was a difference between the fatigue rating reported by the MS group and the control group, a one-way ANOVA was run on the overall fatigue ratings. Subsequently, a repeated measures ANOVA was used to compare the acoustic measures in a fatigued and nonfatigued state with group and gender as between subjects factors. Tests of significance were evaluated against the null hypothesis of no difference using an alpha level of .05.

Results

The means and standard deviations of the overall fatigue ratings from the participants in the morning and the afternoon are reported in Table 2. These ratings were compared using a one-way ANOVA and significant differences were found between the fatigue levels reported by participants with MS and the controls in both the fatigued, $F(1, 22) = 27.24$, $p < .001$), and nonfatigued states, $F(1, 21) = 19.33$, $p < .001$. The MS group had higher fatigue ratings than the control group in both the nonfatigued and fatigued states and reported a greater difference between the two states than the control group.

Because only two of the speakers were perceptibly dysarthric, significant differences in the speech variables between the two groups were not anticipated. A one-way ANOVA performed on the speech variables found no significant difference between the participants with MS and the control group except in duration of the diphthongs /aɪ/ $F(1, 22) = 5.89$, $p = .024$ and /aʊ/ $F(1, 22) = 5.00$, $p = .036$ in the nonfatigued state. The duration of the diphthong /ɔɪ/ reached significance at the .10 level in the nonfatigued state, $F(1, 22) = 3.16$, $p = .090$. The means and standard deviations for diphthong duration reported in Table 3 show that the MS group had longer diphthong durations than the control group in the nonfatigued state. Results from other measured variables did not reach significance and are reported in Appendix E.

Table 2

Means and Standard Deviations of Overall Fatigue Ratings in a Fatigued and Nonfatigued State

Group	Nonfatigued *M* (*SD*)	Fatigued *M* (*SD*)	Difference *M* (*SD*)
Control	13.05 (3.55)	16.13 (5.66)	2.95 (3.46)
MS	22.05 (5.79)	28.64 (5.84)	6.59 (4.02)

Table 3

Means and Standard Deviations of Diphthong Duration (in seconds) in a Nonfatigued State

Group	/aɪ/ *M* (*SD*)	/aʊ/ *M* (*SD*)	/ɔɪ/ *M* (*SD*)
Control	0.10 (0.02)	0.12 (0.02)	0.13 (0.04)
MS	0.12 (0.02)	0.14 (0.03)	0.17 (0.06)

Univariate repeated measures ANOVAs on all acoustic variables with fatigue state as the within subjects factor and group and gender as between subjects factors found no significant main effects or interactions at an alpha level of .05.

Although no statistically significant group results were found that were consistent with previous studies investigating F2 transitions, visual examinations of the formant tracks of the speaker with moderate dysarthria compared to an age-and gender-matched control showed some of the expected acoustic features of dysarthria in individuals with MS. The dysarthric speaker's F2 transitions showed more variability and were generally smaller than those of the age-matched control. When the control speaker said the diphthong /aɪ/, the F1 track gradually rose and fell, while the F2 track gradually rose throughout the diphthong (see Figure 1). The same transitions for the speaker with MS were much shallower, particularly in the fatigued state, with F2 showing very little transition. In the nonfatigued state the F2 transition was larger than in the fatigued state, but the duration of the diphthong was longer than for the control. F1 was similar in both the fatigued and nonfatigued states, but still had less movement than for the control speaker (see Figures 2 and 3). Although no generalizations can be drawn from the visual examination of these formant histories, it is interesting to note the differences in the F1 and F2 transitions in the two conditions, but it is impossible to determine if the differences are due to fatigue or other variables. A more extensive study involving a greater number of dysarthric speakers might be more conclusive.

Discussion

Because many individuals with MS identify fatigue as a symptom that affects them physically and cognitively, this study was undertaken to determine how it might influence selected acoustic properties of speech in individuals with MS. Intelligibility of dysarthric speakers has been linked to F2 transitions (Hartelius, 2000; Rosen et al., 2008; Tjaden & Wilding, 2004). In order to better understand how the speech of dysarthric individuals with MS is affected by fatigue, the present study examined the F2 slopes of three diphthongs that

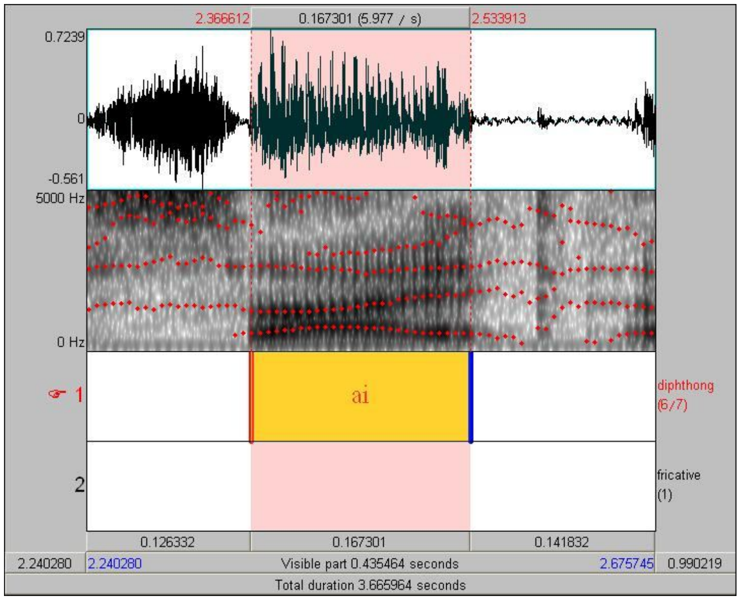

Figure 1. Formant tracks for the diphthong /aɪ/ from an age- and gender-matched control of the speaker with moderate dysarthria.

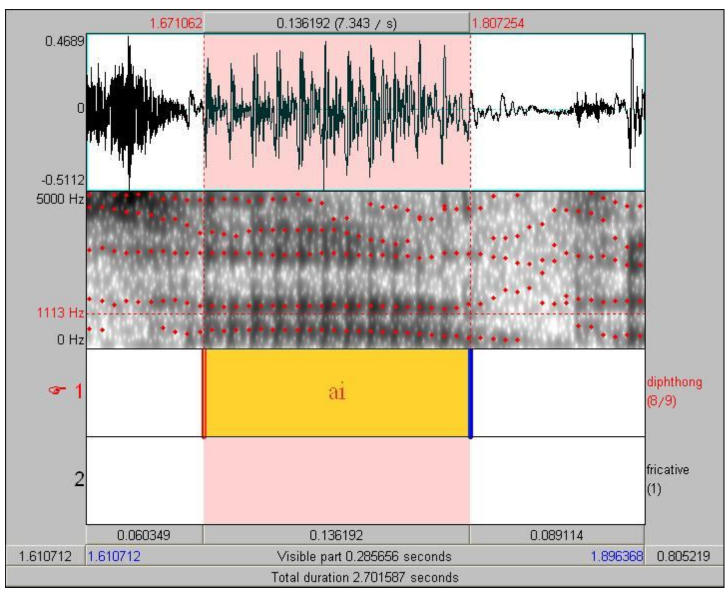

Figure 2. Formant tracks for the diphthong /aɪ/ from an individual with moderate dysarthria in a fatigued state.

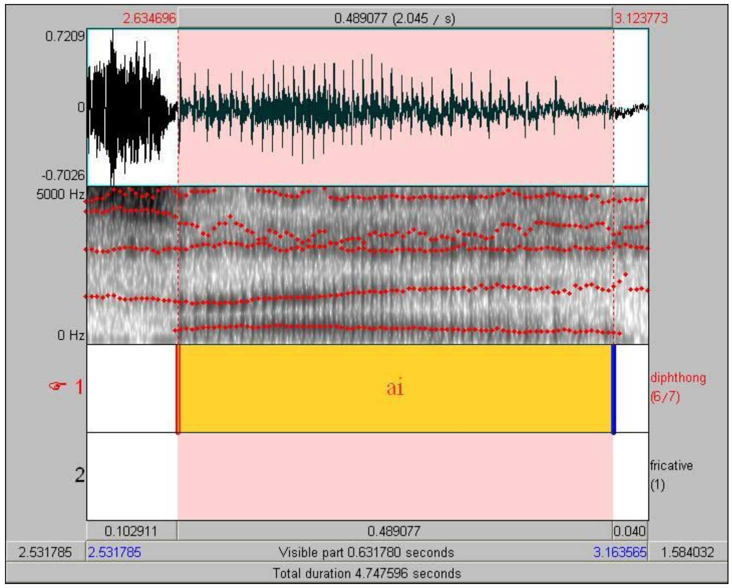

Figure 3. Formant tracks for the diphthong /aɪ/ from an individual with moderate dysarthria in a nonfatigued state.

were spoken in both a fatigued and nonfatigued state. The only significant differences were between the MS and control groups' overall fatigue ratings and the diphthong durations in a nonfatigued state. There were no significant differences between groups or conditions for the F2 transitions and slopes.

In general, the relatively small number of dysarthric speakers recorded is a limiting factor in this study. As discussed earlier, the literature suggests that dysarthria in MS occurs more frequently as the disease progresses, affecting mobility and other systems (Darley et al., 1972; Hartelius, Runmarker, & Anderson, 2000; Yorkston et al., 2003), so it is understandable that fewer dysarthric speakers would be willing to travel to participate in a speech research study. Even though a number of the individuals who participated indicated in the telephone interview that they experienced speech anomalies similar to dysarthria during

MS exacerbations, these speech impairments were not apparent in connected speech during the recording sessions for this study.

Because the fatigue experienced by people with MS is pervasive and seems to have both a PNS and CNS component (Sharma et al., 1995), a number of different methods for measuring fatigue have been used. These methods include visual analog scales (VAS), questionnaires, and the individual's ability to complete a task involving muscle force. Questionnaire measures have been shown to be an effective tool in assessing fatigue in people with MS, while self-report scales have good concurrent validity (Chipchase, Lincoln, & Radford, 2003). In this study, the process of computing a fatigue score included averaging the answers to a questionnaire with the individual's personal fatigue rating. Using this process the participants with MS, as a group, rated themselves higher in both a nonfatigued and a fatigued condition. Additionally there was a greater difference between the MS group's fatigued and nonfatigued states than was the case for the control group. These differences between the MS group and the control group indicate that the questions asked in the fatigue survey combined with the self-reported fatigue scale differentiated the MS participants from the controls and were adequate in describing the feeling of fatigue individuals with MS experience as compared to the controls.

With one exception, fatigue conditions did not affect acoustic measures of the diphthongs. The only significant difference was the longer diphthong duration for speakers with MS in a nonfatigued state. While this difference was significant in a nonfatigued state, there was no difference between the groups in a fatigued state (see Appendix E). It was expected that if diphthong duration were affected by fatigue, the impact would have been greater in a fatigued state than a nonfatigued state. This disparity does not lend itself to a straightforward explanation and illustrates the variability in performance of the speakers in this study. Since reduced speech rate is common to many types of dysarthria, it may have accounted for the longer diphthong durations. Because this study included only two individuals whose speech was perceptually dysarthric, further study with a larger sample of dysarthric individuals is needed to better understand the speech disorder that can result from MS.

While some studies have found that selected acoustic measures, such as those reflecting phonatory instability, may act as subclinical indicators of dysarthria (Hartelius et al., 1995), differences in F2 transitions were only seen by visual examination of spectrograms for those speakers who were judged to have a perceptible dysarthria, and even these observations were variable. Tjaden and Wilding (2004) reported that F2 slopes tended to be more shallow for speakers with dysarthria, and a visual examination of the moderately dysarthric individual confirmed that F2 was shallower in both the fatigued and nonfatigued state for the diphthongs /aɪ/ and /aʊ/. In a visual examination of the diphthongs produced by the speaker with mild dysarthria, it was more difficult to see a clearly shallower slope than for the age- and gender-matched control, but again this could be attributed to the mildness of the dysarthria this individual exhibited. Overall, the extent and slope of F2 transitions for individuals not experiencing dysarthria were not significantly different from their age- and gender-matched controls, which could be attributed to the variability in MS. Additionally, when measuring instantaneous F2 slope for all transitions (not just diphthongs), Rosen et al. (2008) found that differences in F2 slope in a mild dysarthria were easier to discern within the phonetic contexts of high front vowels, diphthongs, or glides. The present study measured the slope of the transition of diphthongs and did not find significant differences between the speakers with MS and the control group. The differences between the findings of the two studies may be attributable to the different types of slopes measured, as well as the relatively few speakers in this study who were determined to have even a mild dysarthria.

When Solomon induced lingual fatigue in normal speakers (2000), it was noted that the F2 transition for the diphthong /ɔɪ/ was significantly shallower during a fatigued state. Therefore, a difference in the extent of F2 transitions might have been expected in the current study. While a shallower slope was observed from a visual examination of the diphthongs /aɪ/ and /aʊ/ of the speaker with moderate dysarthria, this was not the case for the diphthong /ɔɪ/. The slope for /ɔɪ/, even with its greater difference between onset and offset than the other two sounds, was similar for both the dysarthric speaker with MS and the control. A possible explanation for the disparity between the findings from Solomon's study and the current investigation may lie in the different types of fatigue that were examined–a task-induced fatigue of a particular group of muscles versus the self-report of a more pervasive fatigue.

Fatigue is difficult to quantify, and the types of fatigue and their effect on individuals can be variable. While Solomon (2000) did observe speech differences in normal speech when lingual fatigue had been induced, she did not observe significant differences in the acoustic measures of speech in individuals with PD after a speech-like task was used to induce fatigue (2006). The present study considered a pervasive fatigue with both central and peripheral components. While a number of participants reported feeling fatigued and rated themselves as more fatigued than the control subjects, fatigue did not seem to affect their perceived level of speech impairment, and it did not affect the acoustic measures of formant transitions. These observations are similar to Solomon's findings and corroborate her assertion that the articulation system is robust and resistant to fatigue.

Even though the findings of this study support the idea that the articulation system is fatigue resistant, speakers with MS in previous studies have provided anecdotal evidence that more effort is required to communicate and be understood when they are fatigued (Yorkston et al., 2001). Additionally, many of the participants in the present study indicated during the screening interview that speech and articulation difficulties were more frequent when they were experiencing exacerbations. It would be interesting to examine dysarthria in MS as it coincides with disease exacerbations to learn how fatigue might affect speech acoustic measures. Future examinations of the fatigue and the perceived speech impairment of people with dysarthria associated with MS could also include characteristics of their speech other than formant transitions in diphthongs. For example, the temporal elements of speech could be investigated to determine if these elements are more prone to the effects of fatigue and whether they make the speaker more difficult to understand. Phonatory instability could also be analyzed to discover if there are variations that can be linked to an individual's fatigue state. The perceptually dysarthric speaker in the present study appeared to have shallower formant transitions for some diphthongs than the matched control, which would be expected in light of previous studies that have documented reduced formant transitions in dysarthria. The present study was limited by both the variability between speakers with dysarthria and their modest level of speech impairment. Future studies with more severely impaired speakers would be valuable in furthering our understanding of dysarthria in MS. The nature of MS makes it difficult to control for variability between speakers, but much could be learned from a study that included a greater number of dysarthric speakers.

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Appendix A

Initial Letter

Dear (Name of Patient),

Two 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.

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 and Kate King, 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

Appendix D

Fatigue Survey

Before each recording session, participants self-rated their current level of fatigue and answered questions to try and qualify the fatigue they were feeling. Participants were asked to rate their current level of agreement with the following statements, using the following scale: Strongly Disagree (SD), Disagree (D), Agree (A), Strongly Agree (SA).

I am having difficulty concentrating.	SD	D	A	SA
I am having difficulty organizing my thoughts.	SD	D	A	SA
I am having difficulty paying attention.	SD	D	A	SA
I am having difficulty thinking fast enough.	SD	D	A	SA
I am having difficulty staying alert.	SD	D	A	SA
I am having difficulty staying interested.	SD	D	A	SA
I am having difficulty doing things that require physical coordination.	SD	D	A	SA
I am having difficulty doing things that require physical effort.	SD	D	A	SA
My muscles feel weak.	SD	D	A	SA
I feel clumsy.	SD	D	A	SA

Please rate your current overall feeling of fatigue: 1=Not Fatigued, 2=Mild Fatigue, 3=Moderate Fatigue, 4=Severe Fatigue.

Appendix E

Nonsignificant Results

Means and Standard Deviations of Diphthong Transitions (Hz) in Fatigued and Nonfatigued states

	Nonfatigued State		Fatigued State	
Variable	*M*	*SD*	*M*	*SD*
/aɪ/ F1 transition MS	-177	106	-143	91
Control	-149	98	-121	96
/aɪ/ F2 transition	366	204	376	211
Control	410	239	371	305
/aʊ/ F1 transition MS	-59	100	-65	92
Control	-69	77	-76	83
/aʊ/ F2 transition MS	-277	134	-314	149
Control	-198	315	-193	314
/ɔɪ/ F1 transition MS	-15	38	-27	26
Control	-45	53	-2	55
/ɔɪ/ F2 transition MS	982	274	964	312
Control	844	275	873	274

Means and Standard Deviations of Slopes (Hz/ms) for Diphthongs in Fatigued and Nonfatigued states

	Nonfatigued State		Fatigued State	
Variable	*M*	*SD*	*M*	*SD*
/aɪ/ F1 slope MS	-1447	961	-1283	751
Control	-1457	948	-1197	749
/aɪ/ F2 slope MS	3102	1668	3278	1560
Control	4215	2088	3734	2468
/aʊ/ F1 slope MS	-319	682	-358	542
Control	-545	619	-589	613
/aʊ/ F2 slope MS	-1890	784	-2247	1105
Control	-1621	2684	-1649	2284
/ɔɪ/ F1 slope MS	-162	312	-227	248
Control	-377	411	-77	403
/ɔɪ/ F2 slope MS	6246	1520	6548	1856
Control	6848	2305	6960	1750