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Acoustic variation during passage reading for speakers with dysarthria and healthy controls

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Abstract

Purpose—Acoustic variation in a passage read by speakers with dysarthria and healthy speakers was examined.

Method—15 speakers with Multiple Sclerosis (MS), 12 speakers with Parkinson's disease (PD), and 14 healthy speakers were studied. Acoustic variables included measures of global speech timing (e.g., articulation rate, pause characteristics), vocal intensity (e.g., mean sound pressure level and intensity modulation), and segmental articulation (i.e., utterance-level second formant interquartile range (F2 IQR)). Acoustic measures were obtained from three segments operationally defined to represent the beginning, middle, and end of a reading passage. Two speaking conditions associated with common treatment techniques for dysarthria were included for comparison to a habitual speaking condition. These conditions included a slower-than-habitual rate (Slow) and greater-than-habitual intensity (Loud).

Results—There was some degree of acoustic variation across the three operationally-defined segments of the reading passage. The Slow, Loud and Habitual conditions yielded comparable characteristics of variation. Patterns of acoustic variation across the three passage segments also were largely similar across speaker groups.

Conclusions—Within-task acoustic variation during passage reading should be considered when making decisions regarding speech sampling in clinical practice and research. The contributions of speech disorder severity and linguistic variables to within-task acoustic change warrant further investigation.

Learning outcomes—Readers will be able to (1) discuss the motivation for studying and understanding within-task variation in contextual speech, (2) describe patterns of acoustic variation for speakers with dysarthria and healthy speakers during passage reading, (3) discuss the relationship between non-habitual speaking conditions and within-task variation, (4) understand the need to consider within-speaker, within-task variation in speech sampling.

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Keywords

speech production; dysarthria; acoustics

1. Introduction

Passage reading is widely used in dysarthria research and clinical practice. Commonly used passages include “The Grandfather Passage” (Darley, Aronson, & Brown, 1969a, 1969b; Reilly & Fisher, 2012), the “Rainbow Passage” (Fairbanks, 1960), “The Farm script,” (Crystal & House, 1982), the “Hunter script,” (Crystal & House, 1982), “The John Passage,” (Tjaden & Wilding, 2004), and “The Caterpillar” (Patel et al., 2013). Compared to other structured speech tasks such as sentence production, passage reading is suggested to better approximate the requirements for spontaneous speech (Duffy, 2013; Patel et al., 2013). Unlike spontaneous speech, however, passage reading offers structure and control over the content produced, which is helpful for clinicians and researchers to document and describe behaviors, particularly when characterizing dysarthria (Patel et al., 2013). In addition, linguistic and prosodic aspects of speech can be considered within a controlled context (see also Patel et al., 2013).

Passage reading further allows for an examination of speech production over a longer span of time when compared to structured tasks like sentence production. For example, Yunusova and colleagues (2005) examined the acoustic basis of intelligibility variation over the course of a passage read by persons with Parkinson’s disease (PD) or Amyotrophic Lateral Sclerosis (ALS) and by healthy controls. Results indicated that length of grammatical units and second formant interquartile range (F2 IQR), a global index of segmental integrity for vocalics, were related to intelligibility variation over the course of passage reading. Additionally, speakers with PD and ALS whose intelligibility was poorer produced more variable breath group durations over the course of the reading passage compared to speakers with relatively better intelligibility. In another study, Skodda and Schlegel (2008) examined speech timing and pause variables at the beginning and end of a passage read by speakers with Parkinson’s disease (PD) and healthy controls. Results indicated an increase in speech rate at the end of the passage for both groups, but speakers with PD increased rate more relative to healthy controls. As suggested by the studies reviewed here, within-task change or variation in dysarthric speech production has received limited research attention in. However, as discussed in the following sections, this type of within-task speech production variability has methodological and theoretical implications for researchers studying dysarthria.

1.1. Passage Reading as a Methodological Issue

Studies of neurologically normal speech suggest the presence of within-task changes in speech produced during passage reading, which has important implications for speech sampling. For example, declination, in the form of fundamental frequency (F0) declination (e.g., Pierrehumbert, 1979; Ladd, 1988) and the analogous articulatory declination (e.g., Vayra & Fowler, 1993), would seem to predict a decrease in F0 and articulatory integrity over time. Physiological fatigue may also affect speech produced over an extended period of

time. Solomon (2000), for example, demonstrated that exercise-induced tongue fatigue contributed to a decrease in second formant (F2) frequency for the vowels /i/ and /u/. Tongue fatigue was also associated with reduced slope of F2 transition for consonant-vowel /tɑ/ and diphthong /ɔɪ/. Similarly, higher lung volume has been reported toward the beginning relative to the end of a reading passage (Winkworth, Davis, Ellis, & Adams, 1994). Thus, in addition to linguistic variation, a variety of sources point to the potential for inherent variation in speech production over the course of passage reading.

Furthermore, it is unclear whether within-task variation could influence stimulated non-habitual speech characteristics, which is a subject of interest in dysarthria. Many management techniques for dysarthria require speakers to voluntarily alter rate, loudness, clarity, or other speech characteristics to facilitate intelligibility, and stimulability testing in which a speaker is instructed to modify speech output is often used to evaluate the potential value of an intervention technique (Yorkston, Beukelman, Strand, & Hakel, 2010). For healthy speakers, Smiljanić and Bradlow (2008) demonstrated that acoustic characteristics of clear speech were comparable over the course of an extended speech task. This finding indicates that healthy speakers were able to maintain a clear speech style over time. However, it is unknown whether speakers with dysarthria are able to maintain stimulated changes in speech style for a period of time. This knowledge is of clinical importance and may help inform decisions concerning candidacy for progressing to a treatment approach or training program.

1.2. Theoretical Relevance of Within-Task Variation

Within-task variation in passage reading is one form of within-speaker variability. Theories and models of healthy speech production have explained variations in production as the manifestation of adaptive behaviors. For example, Lindblom's (1990) H & H theory suggests that changing communicative demands dictate variations in phonetic distinctiveness along a continuum ranging from Hypo- to Hyper-speech. Within the H & H framework, speech tasks are not categorically different. Instead, task differences are always relative on the H & H continuum. Consistent with this concept that speech behaviors operate along a continuum, it has also been hypothesized that the end goals of speech production as motor events are dynamic rather than singular in nature (e.g., target region, Guenther, Hampson, & Johnson, 1998). Moreover, the neural substrates of variations in speech have received attention (e.g., Houde & Nagarajan, 2011; Niziolek, Nagarajan, & Houde, 2013; Sidtis, 2015). Advances have been made in understanding the impact of dysarthria on speech production characteristics and variables that may facilitate intelligibility. However, an account of speech production variability in dysarthria remains elusive (Perkell, 2013; Weismer et al., 2008). Therefore, a systematic examination of within-task variations under different speaking conditions for healthy speakers and speakers with dysarthria may further the understanding of variability in dysarthria (Kent, Kent, Weismer, & Duffy, 2000; Weismer, Tjaden, & Kent, 1995).

1.3. The Present Study

The overarching purpose of this study was to examine acoustic variation over the course of a passage read by speakers with dysarthria and healthy controls. Two research questions were

addressed. First, does within-task variation differ among speaker groups? Second, does within-task variation differ for habitual and non-habitual conditions?

More specifically, acoustic characteristics associated with the beginning, middle, and end of a passage read in three speaking conditions by speakers with dysarthria secondary to PD or MS and by healthy controls were of interest. Speaking conditions included a Habitual condition as well as the non-habitual conditions of Slow (i.e., slower-than-habitual rate) and Loud (i.e., vocal intensity greater-than-habitual). As previously noted, these non-habitual conditions are associated with common treatment approaches for dysarthria. Acoustic measures of global speech timing, vocal intensity, and segmental articulation were of interest owing to their relevance to the different speaking conditions. Measures further were selected to span a variety of speech components or subsystems (i.e., respiratory-laryngeal, articulatory). Variation in speech acoustic measures over the course of a reading passage was the focus of study. Linguistic variation inherent to the reading passage was treated as part of the natural speech variation as in any other unstructured connected speech task. Moreover, by using a single reading passage, linguistic content was the same for all speakers.

2. Methods

2.1. Speaker Characteristics

A total of 41 speakers participated. These speakers also were the subject of previous research reporting acoustic measures of global speech timing and vocal intensity (Tjaden & Wilding, 2004; 2011a). Speakers included 15 individuals with dysarthria reporting a neurological diagnosis of MS (10 women and five men), 12 individuals with dysarthria reporting a neurological diagnosis of idiopathic PD (six women and six men), and 14 neurologically healthy individuals (8 women and 6 men). Participants with MS and PD were recruited from MS or PD support groups and neurology clinics in western New York. Healthy individuals were recruited using posted advertisements. Participants with MS ranged in age from 25 to 62 years (mean=49; SD=10), and participants with PD ranged in age from 42 to 81 years (mean=63; SD=12). Healthy speakers ranged in age from 20 to 77 years (mean= 55; SD= 15).

All participants were native speakers of English, scored at least 25/30 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975), and had pure tone thresholds of 40 dB or better in at least one ear at 1, 2, and 4 kHz (Darling & Huber, 2011; Ventry & Weinstein, 1983; Weinstein & Ventry, 1983). Healthy speakers reported no history of neurological disease. Speakers with dysarthria also reported no history of neurological disease prior to the diagnosis of MS or PD, although one female speaker with MS reported a diagnosis of Bell's palsy associated with her most recent exacerbation approximately five years prior to the experiment. Participants with MS also were taking a variety of symptomatic medications. None of the speakers with dysarthria had participated in the LSVT® treatment program nor had speakers with PD received surgical treatment for PD, although all were taking anti-Parkinsonian medications.

Speakers with MS or PD were further described by dysarthria diagnoses and speech disorder severity estimates. Severity estimates served an important descriptive purpose because a

published intelligibility test was not administered. Briefly, the speakers with MS were judged to have spastic, ataxic, or spastic-ataxic dysarthria ranging from mild to moderate in severity (mild $n=6$, mild/moderate $n=2$, moderate $n=7$). Speakers with PD were judged to have hypokinetic, hyperkinetic, or hypo/hyperkinetic dysarthria ranging from mild to severe (mild $n=3$, mild/moderate $n=1$, moderate $n=5$, moderate/severe $n=2$, severe $n=1$). Dysarthria diagnoses and speech disorder severity estimates reflect the consensus judgment of three speech-language pathologists (SLPs) based on audio recordings of vowel prolongation, diadochokinesis, the Grandfather Passage, and a brief conversational monologue. Diagnostic samples were recorded after the experimental materials (see Procedures below) and were presented to SLPs in a quiet room via loudspeaker. Readers are referred to previous works for more detailed information regarding these procedures (Tjaden & Wilding 2004; 2011a).

2.2. Procedures

Participants were audio recorded while reading the John Passage (Tjaden & Wilding, 2004) in Habitual, Loud, and Slow conditions. The John Passage is a 192-word passage developed to include multiple occurrences of a variety of vowels and consonants. The entire John passage is provided in the Appendix. The Loud and Slow conditions were elicited with magnitude production. All participants first read the passage in the Habitual condition. The order of the remaining conditions was counterbalanced and randomized across speakers. The online recordings were obtained in a sound treated booth. An AKG C410 head-mounted microphone was positioned 9.5 cm from the left oral angle, at a 45 to 50 degree angle from the center of the lips. The signal was pre-amplified, lowpass filtered at 9.8 kHz, and digitized to a personal computer at a sampling rate of 22 kHz using an analog to digital converter with 15 bit resolution. Prior to recording for each participant, a 1000 Hz calibration tone was recorded and saved to computer disk for use in calculating SPL from the acoustic signal. The calibration tone, produced by a function generator, was played through a loudspeaker that was positioned at 9.5 cm from the AKG C410 microphone and the sound level meter. The microphone and the sound level meter were placed parallel to each other. The calibration tone was played at 90 dB, as recorded by the sound level meter, and transduced by the microphone via the same recording specifications for speech samples. Recording sessions for participants with PD began one hour after taking medications. Speakers with MS were recorded during times of the day when individuals reportedly were well-rested. Speakers were paid for their participation.

2.3. Acoustic Analysis

All acoustic analysis was performed with TF32 (Milenkovic, 2005). Previously obtained acoustic measures were reported in aggregate form for the entire reading passage (Tjaden & Wilding, 2004; 2011a). In contrast, because the purpose of the current study was to investigate acoustic variation over the course of passage reading, acoustic measures reported in this study were obtained for three distinct, operationally-defined segments of the reading passage. Characteristics of the segments in the reading passage and dependent variables are discussed further in the following sections.

2.3.1. Operationally-Defined Segments in Reading Passage—Three segments of the 11-sentence John Passage were of interest (Appendix). Segments were selected to include sentences near the beginning, middle and end of the passage while also avoiding potential idiosyncrasies associated with the initial and final sentences. Segments were selected to include a comparable number of words, to coincide with sentence boundaries and to not be immediately adjacent. Segment 1 included sentence three and was comprised of 25 words and 28 syllables. Segment 2 included sentence six and was comprised of 29 words and 37 syllables. Lastly, Segment 3 included sentences nine and ten and was comprised of 26 words and 35 syllables. Thus, Segment 3 was comprised of two sentences in order to have a comparable number of words as other segments.

2.3.2. Dependent Variables—Although a reduction in rate and increased sound pressure level (SPL) are arguably the primary speech production changes accompanying a slower-than-habitual rate and increased vocal intensity, these speech styles also can influence articulation (e.g., Darling & Huber, 2011; McHenry, 2003; Tjaden & Wilding, 2004; Weismer, Laures, Jeng, Kent, & Kent, 2000). It therefore was of interest to also obtain a measure of segmental articulation. F2 IQR (Yunusova et al., 2005) was selected for study because the measure is obtained at the utterance level, comparable to other acoustic measures of interest. As such, acoustic measures of interest spanned the respiratory-laryngeal and articulatory subsystems as well as global speech timing.

Briefly, using the combined waveform and wideband (300–400 Hz) spectrographic displays of TF32 (Milenkovic, 2005), passages were segmented into runs and pauses using conventional acoustic criteria (i.e., stop release burst, voicing energy, frication). TF32's wideband default setting is 300Hz, and this was adjusted as needed based on a given speaker's F0 so that the analysis bandwidth was approximately twice the F0 for optimized visual inspection of the spectrogram. A speech run was operationally defined as a stretch of speech bounded by silent periods between words of at least 200 ms (Tjaden & Wilding, 2004; Turner & Weismer, 1993). Articulatory rate in syllables per second was calculated for each run by dividing the number of syllables produced by run duration. For each speaker and condition, the total number of runs per segment was tallied. Mean run duration (ms) as well as the mean articulatory rate (syllables/second) per run also was calculated for each of the three segments. Speech rate (syllables/second), which reflects the rate of speech produced per unit time including any pauses, also was calculated for each speaker, condition and segment by dividing the number of syllables produced in a segment by the total duration of the segment (i.e., sum of all run and pause durations).

Pauses impact the modulation of speech timing (e.g., Hammen, Yorkston, Minifie, 1994; Hammen & Yorkston, 1996), and pausing is an expression of linguistic organization in speech production, particularly for connected speech (Grosjean & Collins, 1979; Huber, Darling, Francis, & Zhang, 2012) (also see review in Huber et al., 2012). Therefore, for completeness, several pause measures were obtained as a part of the global speech timing measures, although it should be noted that passage segment characteristics constrained the likelihood of pauses. For each speaker, condition and segment, the total number of pauses was tallied and mean pause duration (ms) was calculated. Binary judgments of pause grammaticality also were performed, with a grammatically appropriate pause operationally

defined as a pause occurring between clauses or phrases (Hammen & Yorkston, 1996; Henderson, Goldman-Eisler & Skarbek, 1966). For each speaker, condition and segment, the percentage of grammatically appropriate pauses was calculated and arcsine transformed for statistical analysis. The grammaticality of pauses was documented to supplement pause duration measures. Lastly, the mean duration for grammatical as well as ungrammatical pauses was obtained.

Measures of vocal intensity included measures of overall energy or intensity as well as intensity modulation. For each speaker, condition and segment, the mean SPL for all speech runs was calculated from the RMS voltage trace, with reference to each speaker's calibration tone (see Tjaden & Wilding, 2004). SPL standard deviation (SD) also was obtained for each run from the RMS trace. For each speaker, condition and segment, measures of vocal intensity were averaged to provide a single measure of mean SPL and SPL SD for each segment.

F2 IQR serves as an index of acoustic working space, which has been hypothesized to be an expression of segmental articulatory integrity (Yunusova et al., 2005). F2 frequencies for the duration of all vocalic nuclei were generated from pitch-synchronous Linear Predictive Coding (LPC)-based formant tracks that were manually-corrected as needed. By definition, vocalics included all vowels (i.e., monophthongs and diphthongs), liquids, and glides. Conventional acoustic criteria were used to identify vocalics from the combined waveform and wideband (300–400 Hz) spectrographic displays. Although F2 was traced for nasalized vowels, nasal consonants with identified boundaries from adjacent phonemes were excluded. For each speaker, condition and segment, F2 IQR values were averaged across runs to provide a single composite measure of F2 IQR for each segment.

2.3.3. Measurement Reliability—Measurement reliability for speech run and pause durations was determined by repeating the measures for a random selection of approximately 10% of the data for each speaker. Similarly, binary judgments of pause grammaticality were repeated for a random selection of approximately 10% the data for each speaker. Pearson product moment correlation coefficients (r) and mean signed difference values were used to index reliability. Intrajudge reliability for SPL yielded mean signed difference of .11 dB SPL (SD = .75 dB SPL) and $r = .99$. Interjudge reliability also yielded $r = .99$ and a mean signed difference of .09 dB SPL (SD = .52 dB SPL). Intrajudge reliability for speech run duration yielded a mean signed difference of 12 ms (SD = 50 ms) and $r = .99$. Interjudge reliability for run duration yielded a mean absolute error of 20 ms (SD = 35 ms) as well as $r = .99$. Intrajudge reliability for pause duration yielded a mean signed difference of 15 ms (SD = 47 ms) and $r = .99$. Judgments of pause grammaticality had an intrajudge reliability of $r = .98$. Interjudge reliability for pause yielded a mean signed difference of 16 ms (SD = 26 ms) and $r = .99$. Interjudge reliability for pause grammaticality judgments yielded $r = .97$. Inter-judge and intra-judge reliability for F2 IQR was assessed by repeating the entire F2 IQR measure for approximately 10 % (N = 37) of all segments (3 segments $\times$ 3 conditions $\times$ 42 speakers = 378). The mean signed difference in F2 IQR values between the original and replicate measures was 10.22 Hz, and the mean absolute difference was 20.69 Hz. Inter-judge reliability was $r = .99$. Intra-judge reliability was $r = .99$, with a mean signed difference of -0.69 Hz and a mean absolute difference of 16.13 Hz.

2.4. Data Analysis

2.4.1. Descriptive Statistics—For each of the three speaker groups and speaking conditions, select measures that represent the span of acoustic measures of global speech timing, vocal intensity, and segmental characteristics were examined using cumulative probability distributions. This follows the method outlined in Kim, Weismer, Kent & Duffy (2009). Kim and colleagues (2009) examined F2 slope distributions for a group of speakers with dysarthria secondary to stroke, a group of speakers with dysarthria secondary to PD, and a group of healthy individuals. Briefly, all data points for each selected measure were compiled and arranged as normalized probabilities in ascending order from 0 to 1, where 0.5 corresponds to the median (e.g., Burr, 1942; Massey, 1951). Graphically, a normal distribution expressed as a cumulative probability has a sigmoid function (s-shaped) (Massey, 1951; Waissi & Rossin, 1996). The width of a given plot indicates dispersion, and in the present study it corresponds to the range of variation. Also see section 3.1. Descriptive Findings below.

Distributions, as compared to standard descriptive statistics such as means, provide a more comprehensive characterization of the data and were suitable for the study's primary interest in variation over a span of time (i.e., effects of segments in passage reading). Distributions were calculated separately for each of the three segments of interest in the reading passage for the dependent variables of articulation rate per run (syllables/second), pause duration (ms), SPL per run (dB), and F2 IQR (Hz) per run. As previously indicated, a cumulative probability distribution was generated per speaker group, per condition, and per segment using all data points available from all speakers. For run-level measures of articulation rate, SPL, F2 IQR, values for all available runs were plotted. Similarly, all pause duration measures were included.

2.4.2. Parametric Analysis—Acoustic variation across selected segments in the reading passage was analyzed with linear mixed model analysis using IBM SPSS Statistics (version 21). The three fixed factors of interest included Condition, Segment and Group, with Condition and Segment denoted as repeated. Severity was included as a fixed factor in each model to allow for the evaluation of potential interaction effects with the degree of speech involvement. Speakers were coded for severity of speech involvement based on ratings reported in Tjaden and Wilding (2004; 2011a, 2011b) (see earlier section on Speaker Characteristics). Descriptors of severity were coded with numbers for analysis, with 0 indicating no impairment, 1 indicating mild, 2 indicating moderate, and 3 indicating severe. Ratings with more than one descriptor (i.e., mild/moderate or moderate/severe) were coded with the numerical average that corresponded to both ratings (i.e., mild/moderate = 1.5, moderate/severe = 2.5). The subject (random) factor was Speaker. Main effects of Condition, Segment, and Group were examined. Two-way interactions of Condition $\times$ Group, Segment $\times$ Condition, Segment $\times$ Group, and Severity $\times$ Group were also included in the models. Finally, only the three-way interaction of Segment $\times$ Group $\times$ Severity was evaluated. The interaction terms were selected based on the primary interest in the interaction of Segment with other variables. Note that the interest in Severity pertains to its potential interaction(s) with other factors, but associated post hoc comparisons on these interaction effects were not tested statistically given the small and unequal number of speakers in each severity group.

Study-wide alpha level was held at $p = .05$. Each linear mixed model for each acoustic measure was evaluated at $p = .05/10 = .005$, with ten dependent variables (See Table 1). Post hoc pairwise comparisons were performed with Bonferroni adjustments and evaluated at $p = .05$ for significant main effects of Group, Condition, and Segment.

Dependent variables are listed in Table 1. The majority of data used in the statistical analyses was in the form of raw measures obtained for each speaker, condition and segment. Averages were used for measures obtained across multiple speech runs (e.g., mean run duration). For all other measures, see details in section 2.3.2. Dependent Variables.

3. Results

3.1. Descriptive Findings

Figures 1 through 4 show the cumulative probability distributions for articulation rate per run (syllables/second), pause duration (ms), mean SPL per run (dB), and F2 IQR (Hz). Distributions are presented as a function of speaker Group (columns) and Condition (rows). In each panel, data for Segment 1 are plotted as open circles, Segment 2 as an “x”, and Segment 3 as grey triangles. The dependent variables are shown on the x axis. For a given plot (i.e., distribution curve) the width (x axis) illustrates the range of variation for the variable. A wider plot indicates more variation in the sample, and a narrower plot indicates less variation.

Segment 1 yielded a slower articulation rate and shorter pauses as compared to Segments 2 and 3 for some speakers (Figures 1 & 2), as indicated by the shift of Segment 1 distributions to the left of Segments 2 and 3. SPL was relatively stable across Segments (Figure 3). F2 IQR decreased across Segments in the Habitual condition, as Segment 3 shifted to the left of Segments 1 and 2 (Figure 4). A similar pattern was observed for the Slow condition. In the Loud condition, however, F2 IQR in Segment 2 was much reduced from Segments 1 and 3. The range of F2 IQR values for all speaker Groups was comparable across Conditions. For all other measures, the non-habitual Conditions presented with changes in the expected directions.

In sum, the shape of the distributions across Segments was largely similar, and Segment-to-Segment differences presented mainly as shifts on the x axis (overall increases or decreases). Differences among Segments were limited for SPL and to some extent articulation rate and pause duration. Differences among segments for F2 IQR were greater.

3.2. Parametric Findings

Table 1 reports all significant F tests. Table 2 further reports findings for all significant follow-up pairwise comparisons. There were significant main effects of Segment, Group and Condition for many measures. Table 1 also indicates a significant Severity $\times$ Group interaction for the majority of dependent measures, as well as a few additional isolated interactions. As discussed in the following paragraphs, the main effect of Segment and the interaction of Segment with other factors were of primary interest. Group and Condition effects are reviewed for completeness.

There was a significant effect of Segment for most measures of global speech timing as well as F2 IQR (Table 1, see also Figures 1, 2, & 4). Table 2 indicates that Segment 1 tended to be associated with fewer runs, shorter pauses, and a slower articulation rate compared to other segments. Segment 2 also had significantly decreased F2 IQR when compared to the first and third segments. Segment 3 was associated with an increased articulation rate as compared to Segment 1. In addition, there was a significant Segment $\times$ Group interaction for mean pause duration. Mean pause duration increased throughout the reading passage for healthy speakers. For speakers with MS, however, pause duration was shortest for Segment 2 and longest for Segment 3. For speakers with PD, mean pause duration was shortest for Segment 1 and comparable for Segments 2 and 3. Finally, Table 1 indicates a significant interaction of Severity $\times$ Group for most acoustic measures. This finding is considered further in the Discussion. As previously noted, interaction effects concerning Severity were not subjected to post hoc analyses due to the small and unequal number of speakers across levels of Severity. Nonetheless, to demonstrate the complex effects of Severity, Figure 5 shows the interaction of Severity and Group for four acoustic variables. Acoustic variables in Figure 5 were selected to represent the range of acoustic measures studied. Figure 5 indicates a variety of patterns in the data within the MS and PD groups as a function of Severity. There was only one significant three-way interaction of Segment $\times$ Group $\times$ Severity for mean pause duration.

A significant effect of Group was found for all measures except the percentage of grammatical pauses and vocal intensity modulation, as indexed by SPL SD per run (Table 1). Table 2 further expands upon the group differences. Speakers with dysarthria, when compared to healthy speakers, tended to use more runs that were of shorter duration, as well as longer pauses. For articulation rate, speakers with MS used a slower articulation rate compared to speakers with PD as well as healthy speakers. In terms of vocal intensity, speakers with PD had statistically lower average SPL per run when compared to the healthy speakers. Finally, speakers with MS and PD had significantly decreased F2 IQR per run when compared to the healthy speakers.

A significant effect of Condition was found for all measures except F2 IQR (Table 1). The Loud condition was associated with an increase in vocal intensity, and the Slow condition was associated with decreases in measures of global speech timing. The Condition effects for measures of global speech timing also varied by speaker Group (Table 1), as indicated by a significant Condition $\times$ Group interaction. All speaker groups shared similar patterns of articulation rate variation, but healthy speakers used a rate in the Slow condition that approached the rate used by speakers with MS (also Figure 1).

4. Discussion

The first research question addressed whether within-task variation was different for the MS, PD and healthy control groups. The lack of a significant Segment $\times$ Group interaction for the majority of acoustic measures indicates that within-task variation was not different across the three speaker groups. This result was further supported by the cumulative probability distributions which indicated similar distributions across speaker groups (Figures 1, 2, 3, & 4). In contrast, studies examining repeated productions of the same sentence or utterance

suggest increased speech production variability for individuals with dysarthria (e.g., Dromey, 2000; Kleinow, Smith, & Ramig, 2001; McHenry, 2003; Weismer et al., 2008). While token-to-token variability across productions of the same utterance has long been of interest as a measure of speech motor flexibility and stability (e.g., Smith & Goffman, 1998), this type of variability is different from variation that occurs over a period of time in contextual speech production. One interpretation is that different forms of within-speaker variability could manifest differently. That is, variability may be specific to task and context.

The three speaker groups (healthy control, MS, and PD) presented with different characteristics of global speech timing, vocal intensity, and segmental articulation, as inferred from F2 IQR. In contrast, there were no group differences in percentage of grammatical pauses or intensity variation across speech runs (i.e., SPL SD). The lack of differences in the percentage of grammatical pauses may be explained by the passage segments examined. This outcome may be different if the entire passage was examined for percentage of grammatical pauses (e.g., Huber et al., 2012). Moreover, the level of severity of speech impairment may have contributed to the current result. This study included speakers with MS or PD with mostly mild to moderate dysarthria severity. That is, approximately half of the speakers across the two speaker groups presented with mild or mild-moderate severity and approximately half presented with moderate dysarthria severity. Similar arguments may explain the absence of group differences in SPL SD. Finally, the acoustic changes associated with a slower-than-normal rate and increased vocal intensity presented in the expected directions for the two non-habitual speaking conditions. However, the healthy speakers demonstrated a greater magnitude of speaking rate change than disordered speaker groups.

In general, acoustic variations over time within the passage reading task, as indicated by a significant effect of Segment, were only present for measures of global speech timing and segmental articulation. Specifically, articulation rate increased (Figure 1) toward the end of the passage while F2 IQR showed a trend of decrease toward the end of the passage, except in the Loud condition where F2 IQR decreased in Segment 2 (Figure 4). The increase in rate toward the end of the reading passage is consistent with findings reported by Skodda and Schlegel (2008). A decrease in F2 IQR at the end of the passage when rate was increased also is consistent with studies reporting that a decrease in vowel acoustic contrast or vowel space area is often associated with an increase in rate (e.g., Hustad & Lee, 2008; Perkell, Guenther, Lane, Matthies, & Stockmann, 2004; Tjaden, Rivera, Wilding, & Turner, 2005). Furthermore, the decreased F2 IQR across the three segments in the passage would be consistent with articulatory declination or fatigue, as reviewed earlier (Solomon, 2000; Vayra & Fowler, 1993; Winkworth et al., 1994), even though fatigue for the relatively brief duration of a reading passage is generally not associated with the dysarthria of MS or PD (e.g., Duffy, 2013). The patterns of acoustic change toward the end of the reading passage also were in the opposite directions of clear-speech (Ferguson, 2004; Krause & Braid, 2004; Lam, Tjaden, & Wilding, 2012). Together, results suggest the possibility that toward the end of the reading passage speakers' productions moved in the direction of Hypo-speech (Lindblom, 1990). Declination is a phenomenon that has been documented at the phrase level (e.g., Ladd, 1988; Vayra & Fowler, 1993) and may be a plausible explanation for Hypo-speech at the end of a passage. Another potential explanation would be that the

reading task may have become more natural and easier toward the end of the passage. It is also possible that the Hypo-speech reflected speakers anticipating the end of the task. Finally, the acoustic changes may reflect differences in the linguistic contexts of the three segments, with the last segment associated with acoustic characteristics that resemble Hypo-speech.

It is noteworthy that F2 IQR was statistically decreased in Segment 2 as compared to both Segments 1 and 3 (Table 2), although Figure 4 clearly shows that variations across segments in the Loud condition might have driven the statistical outcome in the Segment comparisons. This pattern is not readily accounted for by any of the proposed explanations for segment effects. One potential explanation could be that the increased vocal intensity interacted with the linguistic context of Segment 2 that contributed to a decrease in articulatory integrity.

The second research question addressed within-task variation in non-habitual as compared to a habitual speaking condition. The absence of a Segment $\times$ Condition interaction indicates that the pattern of acoustic variation over time, here across the length of a passage reading, was not affected by changes in global speech parameters such as rate or intensity. This suggests that non-habitual speech styles presented with within-task acoustic variations that were relatively comparable to those in habitual speech. Thus, within-task variation may be pervasive across speech styles for a given task of the same speech material (e.g., passage reading). One potential explanation for this would be that the speech acoustic characteristics were specific to the linguistic contexts of the three segments studied. A possible implication may pertain to the construct of “language-specific constraints”, as discussed by Ziegler and Ackermann (2013) (pp. 60). That is, the current results may be one piece of evidence that the speech acoustic signal is ultimately governed by the organization of language. A follow-up study that randomizes the ordering of the linguistic contexts across segments throughout a connected speech task would be valuable in addressing this hypothesis. In addition, varying the length of the connected speech task and thus changing the “time points” when different segments occurred during the task would further add to this line of inquiry.

It is noteworthy that F2 IQR did not differ across speaking conditions for the speakers in this study, although both the Slow and Loud conditions have been associated with changes in more conventional measures of articulatory integrity such as the acoustic vowel space (e.g., Mefferd & Green, 2010; Tjaden & Wilding, 2004; Weismer et al., 2000). Specifically, Tjaden and Wilding (2004) demonstrated that vowel space area was the greatest for the Slow condition, followed by Loud and then Habitual. In addition, relative to the Habitual condition, the Slow condition was associated with significantly greater vowel space areas for healthy speakers and speakers with MS. While the same pattern was observed for speakers with PD, the difference in vowel space areas for the Slow and Habitual conditions was not statistically significant. Similarly, although vowel space area was greater for the Loud condition compared to Habitual, this was only statistically significant for the healthy speakers. These findings point to two potential accounts for the lack of condition variation in F2 IQR in the present study. One account may be that individual segments were too short in length to fully capture articulatory behavior. In addition, the above-mentioned possibility that articulation is constrained by language organization would also suggest little change in the same segment across conditions because of the comparable linguistic structure. The

other account may relate to the global nature of F2 IQR. F2 IQR was obtained at the utterance level, and the measure may not be as sensitive to speaking style changes as compared to vowel space measures. No study to date has systematically compared the relationship between vowel space measures and F2 IQR, and additional work is needed systematically comparing the various acoustic measures that have been used as indices of segmental articulation (e.g., Lansford & Liss, 2014).

Several factors should be kept in mind when interpreting the present findings. First, this study examined two groups of speakers with dysarthria classified by neurological diagnosis (i.e., MS or PD). Overall dysarthria severity was included as a factor in the statistical analysis to understand its potential interaction with other fixed factors. Figure 5 suggests these effects were quite variable across acoustic measures, although the small number of speakers in each severity group precludes strong conclusions. How dysarthria severity and dysarthria type manifest in within-task variation warrants further investigation (Kim, Kent, & Weismer, 2011).

Second, this study focused on passage reading, and the inclusion of less-structured tasks such as conversational speech would be valuable (e.g., Huber & Darling, 2011). Third, further understanding the contribution(s) of linguistic variables to within-task variation is important (e.g., Huber & Darling, 2011; Kleinow & Smith, 2000 & 2006). Relatedly, Segment 3 in the passage contained two sentences while Segments 1 and 2 were comprised of single sentences. This may have affected the pause and/or other speech timing characteristics differently in Segment 3. Additionally, the interface between language and speech production warrants further investigation. For example, examining the same set of acoustic characteristics for different speech materials may offer insight into whether acoustic variation over time is linked to the linguistic organization within the materials.

Fourth, this study examined acoustic measures sensitive to dysarthria (e.g., Kim, et al., 2011; Weismer, Yunusova, & Bunton, 2012), and it would be important to study the variation, or lack thereof, in perceptual characteristics. Changes in speech intelligibility and other perceptual measures (e.g., naturalness) and their association to acoustic changes across segments in a connected speech task would be of interest. Yunusova et al., (2005) seemed to suggest that perceptual characteristics remain relatively constant throughout a reading task although more severe impairment may be associated with different within-task changes. However, Feenaughty, Tjaden and Sussman, (2014) reported sizeable variation in scaled intelligibility across sentences produced by speakers with PD who presented with mild impairment. Within-speaker variability may further have significance for understanding of factors contributing to intelligibility of connected speech in dysarthria (e.g., McHenry, 2003; Yunusova et al., 2005).

Finally, in this study three segments within one reading passage were examined, and use of different experimental materials would be important particularly for testing the hypothesis of language organization in speech. As noted earlier, randomizing the order of linguistic materials within a connected speech task would provide additional insight into whether the effects are truly related to linguistic contexts or time within task. Associated with the time factor, changing the length of the connected speech task would also add to this inquiry.

Additionally, comparing speech materials of the same linguistic contexts across different speaking tasks and conditions would address this question as well.

In summary, the current findings suggest that passage reading is associated with some degree of naturally-occurring acoustic variation, especially for measures of global speech timing and segmental articulation. The end, as compared to the beginning, of a reading passage appears to be associated with characteristics of Hypo-speech (Lindblom, 1990). Such within-task variation should be taken into consideration for speech sampling in research and in clinical practice. Although further research is needed, results suggest that speakers with dysarthria do not necessarily present with greater variability in their productions when compared to healthy individuals (e.g., see Weismer et al., 2008). In fact, in a passage reading task, speakers with dysarthria and healthy speakers presented with similar patterns of within-task variations. Further, the present study did not find a statistically significant interaction between acoustic variation in passage reading (i.e., Segment) and speaking condition. The implication is that a non-habitual speech style does not appear to strongly alter speech acoustics over the course of a reading passage in a manner different from habitual speaking, at least not for a passage reading task. Together, results suggest that it should not be assumed that speech acoustic characteristics sampled from different time points within the same connected speech task are equivalent. More importantly, speech production measures or outcomes for materials characterized by different linguistic and phonetic contexts should not be treated as equivalent. Researchers and clinicians alike should carefully document decisions regarding speech sampling and compare productions for materials that are alike.

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Appendix

The John Passage

John planted a seed in his garden. He dug into the sod while humming a tune from the radio. **The song was a fad off key, but John persisted because he was in a keyed up frame of mind from the long work week.** (1) As he worked, John's buddy Todd walked by. Todd was thought to be somewhat of a cad by most, but was known for his stories. **He spun a tale about an eccentric woman who sat on her stoop every night and fed a cod and a shad to the pigeons that cooed from above.** (2) Every time she threw a bit of fish to the birds flying around her hair, she'd comment on how sad the pigeons seemed. Although the woman shooed the pigeons away when their numbers grew too big, the neighbors grew tired of the spectacle and they sued the woman. **The woman decided to give up the pigeons and pursued her love for golf. Every morning at eight o'clock, she teed off at the first hole.** (3) Instead of a golf cart, however, she traveled from hole to hole on her freshly shod horse named Charlie.

Total number of sentences= 11

Total number of words= 192

Excluding beginning 2 sentences (19 words) and final sentence (20 words).

Segment (1): 3rd/11 sentences, contains 25 words with a total of 28 syllables

Segment (2): 6th/11 sentences, contains 29 words with a total of 37 syllables

Segment (3): 9th and 10th/11 sentences, contains 26 words with a total of 35 syllables

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Highlights

- Speakers with dysarthria share similarities in within-task acoustic variations during passage reading with healthy speakers.
- Within-task variation should be considered when using contextual speech tasks.

CEU Questions

1. **Changes in speech production characteristics over a period of time, such as throughout a reading passage, are well-documented and understood.**
TRUE/FALSE
2. **Within-task variation in speech production has potential implications for**
 - A. speech sampling in research.
 - B. using an extended speech task for clinical evaluation of speech disorders.
 - C. the implementation of therapeutic techniques in connected speech.
 - D. All of the above are true.
3. **Which one of the following statements best characterize the patterns of within-task variation across speaker groups?**
 - A. Speakers with dysarthria shared similarities with healthy speakers in within-task variation.
 - B. Healthy speakers presented with greater within-task variation from segment to segment as compared to speakers with dysarthria.
 - C. Speakers with PD presented with decreased within-task variation as compared to speakers with MS or healthy speakers.
 - D. Speakers with MS presented with the greatest extent of within-task variation, followed by speakers with PD, and then healthy speakers.
4. **What are the indications of the current results for within-task variation in non-habitual speaking conditions?**
 - A. Non-habitual conditions present with within-task changes that are drastically different from the habitual condition.
 - B. Within-task variation appears comparable between habitual and non-habitual conditions.
 - C. Within-task changes are greater than condition effects.
 - D. A slower-than-habitual rate elicited within-task changes that were different from both the habitual and louder-than-habitual conditions.

5. What other factors warrant consideration in future investigations of within-task variation?

- A.** Dysarthria severity
- B.** Linguistic variables
- C.** Task nature and/or structure
- D.** Perceptual characteristics
- E.** All of the above are true.

Answers: FALSE, D, A, B, E

Figure 1.
Cumulative probability distributions for articulation rate per run by speaker group, condition, and segment.

Figure 2.
Cumulative probability distributions for pause duration by speaker group, condition, and segment.

Figure 3.
Cumulative probability distributions for SPL per run by speaker group, condition, and segment.

Figure 4. Cumulative probability distributions for F2 IQR by speaker group, condition, and segment.

Figure 5.
Severity by Group distributions for mean articulation rate, mean pause duration, SPL, and F2 IQR.

Table 1

Summary of test statistics of linear mixed model analysis

	Group	Condition	Segment	Condition × Group	Segment × Condition	Segment × Group	Severity × Group	Segment × Group × Severity
Mean Runs per Segment (count)	F (2,230.21) = 21.65 $p < .001^*$	F (2,198.81) = 46.73 $p < .001^*$	F (2,192.09) = 6.74 $p = .001^*$	F (4,195.27)=1.73 $p = .146$	F (4,165.06)=1.34 $p = .257$	F (4,177.96)=1.83 $p = .124$	F (6,202.36)=24.65 $p < .001^*$	F =(12,165.74)=.71 $p = .738$
Mean Run Duration (ms)	F (2,255.73) = 8.12 $p < .001^*$	F (2,153.94) = 30.81 $p < .001^*$	F (2,215.28) = 1.17 $p = .311$	F (4,148.99)=.74 $p = .567$	F (4,125.90)=.72 $p = .580$	F (4,174.08)=.65 $p = .630$	F (6,175.18)=4.56 $p < .001^*$	F =(12,167.74)=.49 $p = .920$
Mean Articulation Rate per Run (syllables/second)	F (2,324.03) = 16.80 $p < .001^*$	F (2,235.43) = 95.00 $p < .001^*$	F (2,215.55) = 11.74 $p < .001^*$	F (4,236.31)=3.30 $p = .012$	F (4,157.70)=.60 $p = .666$	F (4,213.36)=.22 $p = .927$	F (6,319.45)=15.65 $p < .001^*$	F =(12,210.10)=.34 $p = .981$
Speech Rate (syllables/second)	F (2,317.50) = 24.05 $p < .001^*$	F (2,217.44) = 217.45 $p < .001^*$	F (2,225.74) = 7.13 $p = .001^*$	F (4,224.98)=6.86 $p < .001^*$	F (4,156.51)=.78 $p = .540$	F (4,219.75)=1.18 $p = .319$	F (6,310.07)=30.05 $p < .001^*$	F =(12,213.74)=.68 $p = .767$
Total Pause Count (count)	F (2,230.26) = 21.28 $p < .001^*$	F (2,198.00) = 46.79 $p < .001^*$	F (2,192.64) = 6.44 $p = .002^*$	F (4,195.03)=1.70 $p = .153$	F (4,165.22)=1.35 $p = .253$	F (4,177.38)=1.77 $p = .138$	F (6,201.91)=24.04 $p < .001^*$	F =(12,165.24)=.67 $p = .776$
Mean Pause Duration (ms)	F (2,263.01) = 55.96 $p < .001^*$	F (2,170.80) = 10.65 $p < .001^*$	F (2,197.14) = 6.63 $p = .002^*$	F (4,186.05)=.20 $p = .936$	F (4,138.51)=.75 $p = .561$	F (4,162.26)=5.88 $p < .001^*$	F (6,243.20)=17.85 $p < .001^*$	F (12,151.42)=17.85 $p < .001^*$
% of Grammatical Pauses ¹ (percentage)	F (1,287.83) = .04 $p = .845$	F (2,195.85) = 18.98 $p < .001^*$	F (2,232.73) = 5.94 $p = .003^*$	F (4,205.81)=4.08 $p = .003^*$	F (4,166.98)=1.54 $p = .194$	F (2,229.62)=.57 $p = .569$	F (2,287.61)=4.03 $p = .019$	F (4,221.44)=.24 $p = .914$
Mean SPL per Run (dB SPL)	F (2,318.87) = 14.48 $p < .001^*$	F (2,241.36) = 169.07 $p < .001^*$	F (2,213.95) = 2.86 $p = .059$	F (4,242.65)=.64 $p = .633$	F (4,159.69)=.86 $p = .489$	F (4,203.71)=13 $p = .973$	F (6,309.92)=24.92 $p < .001^*$	F =(12,204.24)=.15 $p = 1.000$
Mean SPL SD per Run (dB SPL)	F (2,323.18) = 1.00 $p = .370$	F (2,214.72) = 44.94 $p < .001^*$	F (2,214.61) = .77 $p = .462$	F (4,221.45)=.60 $p = .663$	F (4,141.47)=.11 $p = .980$	F (4,214.86)=.87 $p = .482$	F (6,320.88)=6.94 $p < .001^*$	F =(12,209.77)=.19 $p = 1.000$
Mean F2 IQR per Run (Hz)	F (2,314.16) = 51.75 $p < .001^*$	F (2,210.70) = 2.46 $p = .088$	F (2,222.19) = 30.14 $p < .001^*$	F (4,221.18)=.77 $p = .546$	F (4,159.31)=.65 $p = .626$	F (4,220.00)=1.36 $p = .250$	F (6,309.27)=4.92 $p < .001^*$	F =(12,212.10)=.25 $p = .995$

/. Arcsine transformed. Significant F tests are indicated by *p* values in boldface and marked with an asterisk.

Note.

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Table 2

Summary of post hoc pairwise comparisons with Bonferroni adjustments.

Fixed Factors	Group	Mean Difference ²	p	Condition	Mean Difference	p	Segment	Mean Difference	p
Dependent Variables¹: Runs per segment	Comparison			Comparison			Comparison		
	H - MS	-1.787	< .001	Habitual - Slow	-3.393	< .001	1 - 2	-1.594	.003
	H - PD	-2.287	< .001	Slow - Loud	3.450	< .001	2 - 3	1.271	.024
Run duration	H - PD	682.363	< .001	Habitual - Slow	769.642	< .001			
				Slow - Loud	-960.860	< .001			
	H - MS	.323	< .001	Habitual - Slow	.912	< .001	1 - 3	-.461	< .001
Articulation rate	MS - PD	-.495	< .001	Habitual - Loud	.083	.040			
				Slow - Loud	.089	< .001			
	H - MS	.479	< .001	Habitual - Slow	1.135	< .001	1 - 3	-.270	.012
Speech rate	H - PD	.337	< .001	Slow - Loud	-.996	< .001	2 - 3	-.347	.002
	H - MS	-1.787	< .001	Habitual - Slow	-3.404	< .001	1 - 2	-1.549	.004
	H - PD	-2.262	< .001	Slow - Loud	3.451	< .001	2 - 3	1.227	.032
Pause Duration	H - MS	-287.902	< .001	Habitual - Slow	-113.433	< .001	1 - 2	-132.854	< .001
	MS - PD	-237.970	< .001	Slow - Loud	102.599	.006	1 - 3	-104.724	.017
				Habitual - Slow	.156	.013	1 - 3	-.195	.007
% Gramm. Pauses				Slow - Loud	-.162	.005			
	H - PD	2.417	< .001	Habitual - Loud	-5.474	< .001			
	MS - PD	1.735	.001	Slow - Loud	-6.115	< .001			
Mean SPL				Habitual - Loud	-.987	< .001			
				Slow - Loud	-1.004	< .001			
	H - MS	57.438	.004				1 - 2	92.897	< .001
F2 IQR	H - PD	195.856	< .001				2 - 3	-137.645	< .001
	MS - PD	138.418	< .001						

Note. Only statistically significant comparisons at $p < .05$ are shown.

¹ Some labels for variables are shortened for tabling. Refer to Table 1 for complete descriptions.

² Based on estimated means as reported by SPSS for pairwise comparisons.