Research Article

Consonant Acoustics in Parkinson's Disease and Multiple Sclerosis: Comparison of Clear and Loud Speaking Conditions

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Purpose: The impact of clear speech or an increased vocal intensity on consonant spectra was investigated for speakers with mild dysarthria secondary to multiple sclerosis or Parkinson's disease and healthy controls.

Method: Sentences were read in habitual, clear, and loud conditions. Spectral moment coefficients were obtained for word-initial and word-medial /s/, /f/, /t/, and /k/. Global production differences among conditions were confirmed with measures of vocal intensity and articulation rate.

Results: Static or slice-in-time first moments (M1) for loud differed most frequently from habitual, but neither loud nor clear enhanced M1 contrast for consonant pairs. In several instances, the clear and loud conditions yielded stable or

nonvarying fricative M1 time histories. Spectral contrast was reduced for word-medial versus word-initial consonant pairs.

Conclusion: The finding that the loud and especially clear condition yielded fairly subtle changes in consonant spectra suggests these global techniques may minimally enhance consonant segmental production or contrast in mild dysarthria. The robust effect of word position on consonant spectra indicates that this variable deserves consideration in future studies. Future research also is needed to investigate how or whether consonant production bears on the improved intelligibility previously reported for these global dysarthria treatment techniques.

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The World Health Organization's International Classification of Functioning Disability and Health (ICF; World Health Organization, 2007) provides a useful framework for contextualizing dysarthria intervention (Duffy, 2013; Dykstra, Hakel, & Adams, 2007; Yorkston, Beukelman, Strand, & Hakel, 2010). Treatment techniques with the potential to enhance speech component function or physiology (i.e., respiration, phonation, resonance, articulation) address the body function and structure level of the ICF, whereas techniques aimed at maximizing intelligibility address the activity level of the ICF. Finally, techniques facilitating involvement in everyday speaking situations address the participation level of the ICF. Relationships among the three primary ICF levels are often complex

in dysarthria (Donovan, Kendall, Young, & Rosenbek, 2008; Dykstra et al., 2007; McAuliffe, Carpenter, & Moran, 2010). For example, impaired function or physiology in one or more speech components may be accompanied by minimal reduction in intelligibility. On the other hand, communication effectiveness or participation may be severely curtailed despite near normal intelligibility. The likelihood of non-linear relationships among ICF levels suggests that the best dysarthria treatments are those with the potential to effect improvements or change at more than one level (Hustad & Weismer, 2007). As discussed in the following section, global treatment techniques such as clear speech or an increased vocal intensity hold much promise in this regard, particularly with respect to the body function and structure level of the ICF, as well as the activity level of the ICF (Yorkston, Hakel, Beukelman, & Fager, 2007).

The benefits of clear speech or an increased vocal intensity for intelligibility in dysarthria, as well as related ICF activity-level perceptual constructs such as speech severity, have been demonstrated in a variety of studies (e.g., Beukelman, Fager, Ullman, Hanson, & Logemann, 2002; Cannito et al., 2012; Neel, 2009; Stipancic, Tjaden, & Wilding, 2016; Tjaden, Sussman, & Wilding, 2014; Wenke, Theodoros, & Cornwell, 2008). The holistic nature of global dysarthria treatment techniques further suggests

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the potential for these techniques to simultaneously impact multiple speech components (i.e., respiration, phonation, resonance, articulation) or the body function and structure level of the ICF. For example, both clear speech and an increased vocal intensity are associated with respiratory–phonatory changes in the form of increased mean sound pressure level (SPL) and fundamental frequency (F0), as well as enhanced modulation or range of sentence-level SPL and F0 (e.g., Lam & Tjaden, 2016; Neel, 2009; Sapir, Ramig, & Fox, 2011; Tjaden, Kain, & Lam, 2014). Clear speech also is consistently accompanied by lengthened segment durations as well as a slower than normal articulation rate (Goberman & Elmer, 2005; Tjaden, Lam, & Wilding, 2013), and some dysarthria studies also have found that an increased vocal intensity is accompanied by lengthened speech durations and a slower than normal rate (e.g., Darling & Huber, 2011; Dromey, 2000; Tjaden, Lam, & Wilding, 2013). Finally, the impact of an increased vocal intensity on velopharyngeal function appears to depend on the nature of the dysarthria (McHenry & Liss, 2006). The effect of clear speech on velopharyngeal function in dysarthria has not been systematically studied, although clear speech has been identified as a promising therapeutic technique for mild velopharyngeal impairment in the form of hypernasality (Yorkston et al., 2001).

Impaired articulation is common in dysarthria (Duffy, 2013). It therefore is not surprising that segmental articulatory changes accompanying clear speech and an increased vocal intensity in dysarthria have been studied a fair amount. Acoustically, reduced articulatory displacements and speeds in dysarthria manifest as compressed vowel space areas, as well as reduced phonetic contrasts and formant transition rates (e.g., Lansford & Liss, 2014; Weismer & Kim, 2010). Kinematic studies of dysarthria further suggest that the therapy techniques of clear speech or an increased intensity are associated with increased lip and jaw displacements and speeds (Darling & Huber, 2011; Dromey, 2000). Most of what is known regarding how global dysarthria treatment techniques affect segmental articulation, however, comes from studies of vowel acoustics. A common finding across studies is that clear speech as well as an increased vocal intensity enhance spectral contrast among vowels (e.g., Martel-Sauvageau, Roy, Langlois, & Macoir, 2015; Sapir, Ramig, Spielman, & Fox, 2010; Tjaden, Lam, & Wilding, 2013; Whitfield & Goberman, 2014; but see Neel, 2009). These global treatment techniques also are associated with an increase in vowel F2 slope, reflecting a greater rate of vocal tract shape change, at least in some studies (e.g., Dromey, Ramig, & Johnson, 1995; Lam & Tjaden, 2016; Tjaden, Richards, Kuo, Wilding, & Sussman, 2013).

In contrast to the wealth of studies investigating vowel segmental production, current understanding of how clear speech or an increased vocal intensity impact consonant segmental production in dysarthria is based on a small number of studies examining only one of these two therapeutic techniques (Lam & Tjaden, 2016; Tjaden & Wilding, 2004; Wenke, Cornwell, & Theodoros, 2010). None of these

prior studies found a robust effect of clear speech or an increased vocal intensity on consonant spectra or spectral contrast for pairs of obstruents such as /s/ and /ʃ/. However, only word-initial consonants were studied, and domain-initial consonants are characterized by articulatory strengthening relative to domain-medial and domain-final consonants (see review in Cho, 2015). Stated somewhat differently, articulatory gestures earlier in utterances are more forceful as well as more spatially and temporally extreme (Cho, 2015). This may effectively limit further “hyperarticulation” in the context of a global dysarthria treatment technique. Speakers with dysarthria also may have a reduced ability to quickly and efficiently adjust vocal tract shapes for phonetic events such as fricatives that require precise oral articulatory postures. Studies including consonants in multiple word positions would help to address these suggestions. Finally, the effects of clear speech or an increased vocal intensity on consonant production in dysarthria have not been directly compared. Comparative studies are crucial for delineating the relative merits of dysarthria treatment techniques and thus for strengthening the scientific evidence base for clinical decision making.

Thus, the purpose of the current study was to investigate the impact of clear speech as well as an increased vocal intensity on spectral characteristics of word-initial and word-medial consonants for speakers with mild dysarthria secondary to multiple sclerosis (MS) or Parkinson’s disease (PD). Healthy controls were studied for comparison. In this manner, the present study focused solely on the body function and structure level of the ICF. As we and others have suggested, the global therapeutic techniques of clear speech or an increased vocal intensity are appropriate for individuals with mild dysarthria (Hustad & Weismer, 2007; Tjaden, Lam, & Feenaughty, 2015). Speakers with mild dysarthria also are representative of individuals pursuing behavioral treatment (Lam & Tjaden, 2016). Consonant spectra were characterized using the first four spectral moments corresponding to spectral mean, standard deviation, skewness, and kurtosis (e.g., Forrest, Weismer, Milenkovic, & Dougall, 1988). The following research questions were addressed:

1. Do the global dysarthria therapy techniques of clear speech and an increased vocal intensity similarly have an impact on spectral moment coefficients for fricatives (/s/, /ʃ/) and stops (/t/, /k/)?
2. Does word position (i.e., word initial versus word medial) influence spectral moment coefficients for fricatives and stops?

The primary research questions focused on static spectral measures of consonants or measures taken at a single point in time, as in prior dysarthria studies (e.g., Tjaden & Wilding, 2004; Wenke et al., 2010). Studies of normal speech suggest that sibilants are spectrally dynamic, however (e.g., Iskarous, Shadle, & Proctor, 2011). Thus, an exploratory analysis was undertaken to investigate first moment (i.e., spectral mean) time histories for select fricatives.

Method

Speakers

A grand total of 37 speakers were included for study. The PD group was composed of 13 individuals with a medical diagnosis of PD, and the MS group was composed of 11 individuals with a medical diagnosis of MS. In addition, the control group was composed of 13 individuals. The PD group included seven males and six females (mean age = 67 years; $SD = 10$ years), the MS group included five males and six females (mean age = 55 years; $SD = 7$ years), and the control group included seven males and six females (mean age = 62 years; $SD = 9$ years). Participants with MS and PD were primarily recruited through patient support groups. Participants are part of a larger ongoing research project that draws from a database of nearly 80 speakers (e.g., for related articles see Tjaden, Lam, & Wilding, 2013; Tjaden, Richards, et al., 2013; Tjaden, Sussman, & Wilding, 2014). Unless stated differently, the methodological details that follow refer specifically to the 37 speakers in the present study.

Participants were native speakers of American English, had achieved at least a high school diploma, and had visual acuity or corrected acuity adequate for reading printed materials. Hearing aid use was an exclusion criterion. Participants with MS and PD were taking a variety of symptomatic medications, but no participant had undergone neurosurgical treatment for MS or PD. Two female participants with PD had completed the Lee Silverman Voice Treatment (LSVT). Visual inspection of the data for these two speakers indicated no remarkable differences compared with the group mean for the remaining speakers with PD. As such, their data were retained. Control participants reported no history of speech-language disorders. On average, speakers with PD were diagnosed 9 years prior to participation ($SD = 9$ years), whereas speakers with MS were diagnosed 14 years prior to participation ($SD = 8$ years). Five participants with MS had a primary progressive disease course, four participants had a relapsing remitting disease course, and two participants had a secondary progressive disease course. With the exception of one male speaker in the MS group who received a score of 25/30, all speakers scored at least 26/30 on the Standardized Mini-Mental State (Molloy, 1999).

Procedures and methods for obtaining clinical perceptual metrics of intelligibility and speech severity are described in detail in Sussman and Tjaden (2012) for the larger speaker database. Intelligibility was quantified using the Sentence Intelligibility Test (Yorkston, Beukelman, & Hakel, 1996). Procedures for obtaining these intelligibility judgments differed from those described in the test manual (e.g., 37 student listeners were used, sentences were randomized across speakers, single presentation of a given sentence) and are outlined in detail in Sussman and Tjaden (2012). Average intelligibility on the Sentence Intelligibility Test was 89% ($SD = 3\%$; range 84%–95%) for the PD group, and 91% ($SD = 3\%$; range 83%–95%) for the MS group. Scaled judgments of speech severity for “the Grandfather Passage” (Duffy, 2013), an operationally defined perceptual

construct intended to tap into speech naturalness and prosody, also were performed by three speech-language pathologists. Speech pathologists judged speech severity using a computerized visual analog scale, with scale values ranging from “0” (i.e., no impairment) to “1” (i.e., severe impairment). Average scaled speech severity was .51 ($SD = 0.23$; range = .10–.85) for the PD group and .71 ($SD = 0.16$; range = .47–.94) for the MS group. This pattern of reasonably preserved intelligibility in an ideal (i.e., quiet) perceptual environment for the MS and PD groups and/or perceptually obvious speech impairment, as indexed by a perceptual construct such as speech severity, is consistent with descriptions of mild dysarthria (Yorkston et al., 2010).

Experimental Speech Stimuli and Procedure

Speakers were audio-recorded reading aloud 25 Harvard sentences (Institute of Electrical and Electronics Engineers, 1969). Sentences were selected from the larger corpus of Harvard sentences to include multiple occurrences of /t/, /k/, /s/, and /f/ in the word-initial and word-medial positions. Four to six occurrences of /s/ and /f/ in both word positions were identified. Five occurrences of word-initial /k/ and two occurrences of word-medial /k/ were identified. Finally, four occurrences of word-initial /t/ and three occurrences of word-medial /t/ were available in the corpus. Vowel and consonant context varied for tokens within a given consonant and word position (i.e., word-initial /t/), as well as across phoneme categories and word position (i.e., word-initial /t/ versus word-medial /k/). Audio recording took place in a sound-treated or quiet room using high-fidelity recording equipment.

Sentences were read in habitual, clear, and loud conditions. Magnitude production was used to elicit variations in clarity and loudness. Details regarding the specific instructions used to elicit the various conditions may be found elsewhere (e.g., Tjaden, Richards, et al., 2013). For each speaker and condition, a unique random ordering of the 25 sentences was recorded. All speakers first read sentences in the habitual condition. The order in which speakers produced nonhabitual conditions was carefully counterbalanced to control for potential order effects. A calibration tone also was recorded to allow for offline measurement of vocal intensity from the acoustic signal.

Acoustic Measures

Acoustic measures were obtained using TF32 (Milenkovic, 2005). The following sections consider measurement procedures in more detail.

Articulation Rate and SPL

Sentence-level measures of SPL and articulation rate were obtained to verify that the magnitude production paradigm elicited clear and loud conditions that differed from habitual. Sentences were first segmented into speech runs, defined as a stretch of speech bounded by silent periods between words of at least 200 ms. Conventional

acoustic criteria were used to identify run onsets and offsets using the combined waveform and wideband (300–400 Hz) spectrographic displays. Articulation rate, in syllables per second, was determined for each run by counting the number of syllables produced and dividing by run duration. Articulation rates were averaged across speech runs to yield a mean articulation rate for each speaker and condition for use in the statistical analysis. Mean SPL for each speech run also was obtained from the root mean squared (RMS) intensity trace. RMS voltages were exported to Excel and converted to dB SPL with reference to each talker's calibration tone. SPL values were averaged across runs to obtain a mean SPL for each speaker and condition for use in the statistical analysis. Technical difficulties precluded measurement of SPL for the loud condition for one speaker with MS.

Moment Coefficients

The first four spectral moment coefficients (i.e., mean, standard deviation, skewness, kurtosis) were obtained for each consonant production for completeness. As in prior dysarthria studies, however, the first moment coefficient (M1) was of primary interest because the speech production interpretation of M1 is best understood (see review in Koenig, Shadle, Preston, & Mooshammer, 2013). A change in M1 reflects source and/or filter effects. Greater M1 values may indicate a more anterior constriction position (i.e., higher M1 for /t/ versus /k/; higher M1 for /s/ versus /ʃ/). Thus, reduced articulatory displacements and speeds in dysarthria may be associated with a less canonical or more centralized constriction position, such that M1 for lingual-velar consonants such as /s/ or /t/ may be lower compared to healthy controls. Relatedly, M1 for velar /k/ and lingual-palatal /ʃ/ may be higher in dysarthria versus healthy controls, reflecting a more anterior or centralized constriction position. Greater M1 values for fricatives may also indicate a smaller or tighter constriction as well as greater airflow through the constriction. Finally, greater lip rounding (i.e., /ʃ/ versus /s/) is associated with a lowering of M1. These examples assume a constant vocal intensity, as an increase in source level yields more energy at high frequencies and thus increases M1 (Shadle & Mair, 1996).

The primary research questions focused on spectral characteristics of fricatives and stops at a single or static point in time, similar to the manner in which midpoint vowel formant frequencies are used to calculate vowel space area. Audio files were first fast Fourier transformed and pre-emphasis was applied in TF32. Moment coefficients for fricatives then were obtained by centering a 20-ms Hamming window at the temporal midpoint of fricatives (Lam & Tjaden, 2016). Measures obtained at the temporal midpoint of fricatives minimize contextual influences of surrounding phonemes (Iskarous et al., 2011). Fricative onsets and offsets needed for determining fricative midpoints were identified using conventional acoustic criteria. Moment coefficients for stops were obtained for a 20-ms Hamming windowed segment starting at the left edge of the release burst (Tjaden & Wilding, 2004). Finally, for each speaker, condition, and

word position, an M1 difference measure (M1Diff) was calculated to index spectral contrast for pairs of stops and fricatives. Thus, for each speaker, condition, consonant, and word position, M1 values were averaged across tokens and an M1 difference measure for stops and fricatives was calculated as follows.

$$\text{M1Diff}_{(\text{stop})} = \text{Average M1}_{/t/} - \text{Average M1}_{/k/} \quad (1)$$

$$\text{M1Diff}_{(\text{fricative})} = \text{Average M1}_{/s/} - \text{Average M1}_{/ʃ/} \quad (2)$$

Clear speech and an increased vocal intensity have been shown to influence the time-varying spectral properties of vowels in dysarthria, as indexed by F2 slope. Studies of normal speech also suggest time-varying change in M1 for fricatives produced in habitual and clear conditions (e.g., Iskarous et al., 2011; Maniwa, Jongman, & Wade, 2009). It therefore was of interest to explore the impact of clear speech and an increased vocal intensity on fricative M1 time histories. Four prevocalic word-initial /s/ and four word-initial /ʃ/ tokens from the primary analysis were included in this exploratory analysis. Fricatives were followed by both anterior and posterior vowels. M1 was obtained at five time points corresponding to 50%, 62.5%, 75%, 87.5%, and 100% of fricative duration. The focus on the last half of fricatives kept this exploratory analysis tractable while at the same time affording observation of anticipatory vowel effects near fricative offset. That is, studies of neurologically normal speech suggest that for prevocalic /s/, the degree and location of the constriction remains nearly constant until the final 20% of fricative duration (Iskarous et al., 2011). At each time point, M1 values for /s/ or /ʃ/ were averaged across speakers in each group as a function of condition, yielding a single /s/ and /ʃ/ time history for each group and condition.

Reliability of Acoustic Measures

Approximately 10% of stimuli were measured twice to determine measurement reliability. Stimuli were selected quasirandomly to include males and females from all groups and conditions. Pearson product-moment correlations and mean absolute difference measures were used to index reliability.

For intrajudge reliability, the correlations for measures of articulation rate and SPL were 0.98 (mean absolute difference = 0.05 syll/s) and 0.99 (mean absolute difference = 0.21 dB), respectively. For M1, M2, M3, and M4, the correlations between the first and second set of measures were 0.99 (mean absolute difference = 0.073 kHz), 0.98 (mean absolute difference = 0.063 kHz), 0.97 (mean absolute difference = 0.086) and 0.96 (mean absolute difference = 0.241), respectively. For interjudge reliability, the correlations for measures of articulation rate and SPL were 0.99 (mean absolute difference = 0.05 syll/s) and 0.99 (mean absolute difference = 0.20 dB), respectively. For M1, M2, M3, and M4, correlations between the first

and second set of measures were 0.99 (mean absolute difference = 0.074 kHz), 0.97 (mean absolute difference = 0.069 kHz), 0.96 (mean absolute difference = 0.086) and 0.93 (mean absolute difference = 0.403), respectively.

Data Analysis

Descriptive and parametric analyses were used. Using SPSS Version 22 (IBM Corporation, 2013), a multivariate linear model was fit to the dependent variables (i.e., articulation rate, mean SPL, moment coefficients) in this repeated-measures design. Moment coefficient analyses were completed separately for the four consonants of interest. All models included the fixed factors of group (MS, PD, control) and condition (habitual, loud, clear). Models for moment coefficients also included the fixed factor of position (word initial, word medial). Speaker sex was included as a random factor in all models. Follow-up contrasts were made in conjunction with a Bonferroni correction for multiple comparisons. Dynamic change in M1 for word-initial fricatives was explored using linear and curvilinear regression-based procedures. The current study represents an initial effort to directly compare the impact of clear speech or an increased vocal intensity on consonant spectra in dysarthria. Thus, a nominal alpha level of .05 was used to ascertain significance so as not to miss trends of interest.

Results

Sound Pressure Level and Articulatory Rate

Table 1 reports descriptive statistics for articulation rate and SPL. There was a significant group effect, $F(2, 37) = 4.198, p < .05$, for articulation rate. Post-hoc tests indicated faster rates for the PD group versus both the MS and control groups, $p < .05$. The condition effect also was significant, $F(2, 74) = 87, p < .001$. Post-hoc tests were significant for all possible pairwise comparisons, $p < .001$. There also was a significant Group $\times$ Condition interaction, $F(4, 74) = 4.675, p < .01$. Post-hoc tests were conducted to evaluate the source of this interaction. Results indicated that the PD group used a faster rate in the habitual condition compared with the MS group, $p = .042$. The PD group also had a faster rate compared with controls in both the clear, $p = .025$, and loud conditions, $p = .011$. Articulation rate for the PD group's loud condition

also was accelerated compared with the MS group, $p = .028$. Within each speaker group, articulation rate was significantly different among pairs of conditions, $p < .05$. Exceptions included the habitual–loud contrast for both the PD and MS groups.

The statistical analysis for SPL also indicated a significant group effect, $F(2, 37) = 9.190, p = .001$, with the greatest mean vocal intensity for the control group, followed by the PD and MS groups. Post-hoc tests further indicated greater SPL for the control group versus both the PD and MS groups, $p < .01$. The condition effect also was significant, $F(2, 73) = 193.166, p < .001$, and post-hoc tests were significant for all possible pairwise comparisons, $p < .001$. Finally, there was a significant Group $\times$ Condition interaction, $F(4, 73) = 3.371, p < .05$. Post-hoc tests evaluating the source of the interaction indicated no group differences within the habitual condition. For both the clear and loud conditions, however, mean SPL was significantly greater for the control group versus both the PD, $p < .004$, and MS groups, $p < .007$. Finally, for each of the three speaker groups, all pairwise comparisons of condition were significant, $p < .001$.

To summarize, all groups reduced articulation rate and increased SPL for the clear condition relative to habitual. All groups also increased SPL for the loud condition versus habitual, and the control group but not disordered speakers reduced articulation rate for loud. Importantly, for all groups, the magnitude of any reduction in articulation rate was greatest for clear, whereas the magnitude of SPL increase was greatest for loud. The control group also made the greatest adjustments in articulation rate and vocal intensity for clear and loud versus habitual.

First Moment Coefficient (M1)

Table 2 reports M1 descriptive statistics for /t/ and /k/ in the form of means and standard deviations (kHz). For both stops, the group effect was not significant. However, the condition effect for /t/ was significant, $F(2, 697) = 17.63, p < .001$. Table 2 indicates that, on average, M1 values for /t/ were greatest in the loud condition, followed by clear and habitual. Post-hoc tests were significant for all possible pairs of conditions, $p < .013$. There also was a significant position effect for both /t/, $F(1, 697) = 51.53, p < .001$, and /k/, $F(1, 709) = 69.118, p < .001$. Table 2 indicates greater M1 values for /t/ and lower M1 values for /k/ in the word-initial position. Finally, there were no significant interactions for either stop consonant.

Table 1. Means and standard deviations for articulation rate and vocal intensity are reported as a function of group and speaking condition.

Group	Articulation rate (syllable/second)			Intensity (dB SPL)		
	Habitual	Clear	Loud	Habitual	Clear	Loud
Control	3.77 (0.52)	2.40 (0.43)	3.21 (0.50)	73.69 (2.37)	78.90 (4.54)	84.51 (4.26)
MS	3.30 (0.80)	2.65 (0.83)	3.09 (0.85)	70.65 (2.56)	74.87 (3.17)	78.76 (2.06)
PD	3.98 (0.62)	3.10 (0.74)	3.90 (0.77)	71.98 (2.46)	74.83 (3.41)	79.25 (2.91)

Note. MS = multiple sclerosis; PD = Parkinson's disease.

Table 2. Descriptive statistics for first moments (M1) in the form of means and standard deviations are reported for /t/ and /k/ as a function of group, condition, and position.

Group	M1 _{/t/} (kHz)						M1 _{/k/} (kHz)					
	Habitual		Clear		Loud		Habitual		Clear		Loud	
	Initial	Medial	Initial	Medial	Initial	Medial	Initial	Medial	Initial	Medial	Initial	Medial
Control	5.155 (0.844)	4.637 (0.939)	5.381 (0.898)	5.136 (0.979)	5.799 (0.856)	5.134 (1.009)	3.483 (1.283)	4.233 (0.865)	3.567 (1.290)	4.548 (0.734)	3.337 (1.170)	4.260 (0.779)
MS	5.290 (1.032)	5.151 (0.910)	5.471 (0.734)	5.065 (1.141)	5.705 (0.977)	5.470 (1.235)	3.493 (1.289)	3.800 (1.229)	3.661 (1.318)	4.324 (1.148)	3.629 (1.417)	4.296 (0.883)
PD	4.911 (0.743)	4.662 (0.849)	5.242 (0.833)	4.869 (0.752)	5.543 (0.923)	4.779 (1.299)	3.508 (1.466)	4.162 (0.966)	3.258 (1.248)	4.245 (0.824)	3.511 (1.480)	4.591 (0.937)

Note. MS = multiple sclerosis; PD = Parkinson's disease.

Table 3 reports M1 descriptive statistics for /s/ and /ʃ/. Once again, the group effect was not significant. However, there was a significant condition effect for both /s/, $F(2, 1128) = 6.009, p = .002$, and /ʃ/, $F(2, 779) = 28.353, p < .001$. Post-hoc tests for /s/ indicated significantly greater M1 values only for loud versus habitual, $p = .002$. Post-hoc tests for /ʃ/ indicated greater M1 values for loud versus habitual as well as clear, $p < .001$. Finally, the position effect was significant for /s/, $F(1, 1127) = 23.542, p = .001$. Table 3 indicates higher M1 values for /s/ in the initial position. Similar to analyses for stops, there were no significant interactions.

Figure 1 reports average M1 difference measures and standard deviations for fricatives and stops as a function of group and condition. Greater difference measures indicate greater spectral contrast among pairs of stops or fricatives. For stops shown in the lower panels of Figure 1, only the main effect of position was significant, $F(1, 178) = 121.68, p < .001$. The greater height of blue versus green bars in the lower half of Figure 1 indicates that stops in the initial position were characterized by greater M1 difference. Similar results held for fricative M1 difference. Fricatives in the initial position were produced with a greater M1 difference, as indicated by a significant position effect, $F(1, 181) = 22.854, p < .001$. There also was a significant Group $\times$ Position $\times$ Condition interaction for fricative M1 difference, $F(4, 182) = 2.494, p = .045$. The source of the interaction is suggested in the upper panels of Figure 1. For example, fricative M1 difference measures in the clear condition for the PD group were nearly identical in both the word-initial and word-medial positions. The MS and control groups, however, demonstrated greater spectral contrast in clear for fricatives in the word-initial position, with this trend being most pronounced for the MS group.

Higher Moments: M2, M3, M4

As previously noted, M1 was of primary interest, and statistical analyses for M2, M3, and M4 were undertaken for completeness. Table 4 summarizes statistical outcomes for these higher moments. Similar to findings for M1, Table 4 indicates that the group effect was not significant for M2, M3, or M4, although there were sporadic instances of significant two-way or three-way interactions involving group, usually for M3. The most consistent finding for M2, M3, and M4 was a significant condition effect. Post-hoc test results summarized in Table 4 indicate that the habitual condition typically differed (i.e., smaller values) from both clear and loud. The direction of any differences for clear and loud were not systematic. There also were a few instances in which the main effect of position was significant or an interaction involving position was significant. Finally, half of the significant results in Table 4 occurred for M3. Results also were more often significant for fricatives than stops.

Fricative M1 Time Histories

Figure 2 plots M1 fricative time histories as a function of consonant (rows), group (columns), and condition

(color). Aside from small differences in relative position on the y-axis, visual inspection of Figure 2 suggests that time histories for all groups and conditions have a concave shape characterized by a marked lowering of M1 between the fourth and fifth time points, for /s/ as well as /ʃ/. In support of this observation, a quadratic function fit to each time history in Figure 2 was significant (i.e., $p = .05$ to $< .001$), with goodness of fit ranging from $R^2 = .16$ to $R^2 = .48$ (mean $R^2 = .27$; $SD = .09$).

The large decrease in M1 time histories between the final two time points reflects the contextual effects of the upcoming vowel (Iskarous et al., 2011). Time histories appear to be relatively flat (i.e., constant) when the fifth or final time point at the fricative + vowel boundary is disregarded in Figure 2. To evaluate this suggestion, linear regression functions were fit to M1 time histories, excluding the final time point corresponding to 100% on the x-axis of Figure 2. Regressions associated with a significant linear fit for these curtailed time histories may be interpreted as having a slope significantly different from zero, meaning that M1 was not constant over the course of the fricative production and changed in a systematic linear fashion. Table 5 reports R^2 and p values associated with the linear fits to these curtailed M1 time histories. Bolded cells indicate significant functions. The sign of the slope for all significant functions was negative or was effectively zero, ranging from -0.169 to 0.006 (mean $b = -0.096$, $SD = 0.049$). Results for /s/, reported in the left columns of Table 5, are considered first. For the control group, no slope was significantly different from zero. For both the PD and MS groups, however, the habitual condition was associated with slopes significantly different from zero, $p < .05$. Interestingly, slopes in the clear and loud conditions for the PD and MS groups followed the pattern for controls, such that slopes were not significantly different from zero. For /ʃ/, Table 5 indicates that slopes for the majority of regression functions were significantly different from zero, with p values ranging from .006 to .022. The Clear condition yielded null slopes for both the control and PD groups, with p values of .134 and .086, respectively.

Discussion

Studies comparing clear speech and an increased vocal intensity are critical for delineating the relative merits of these global dysarthria therapy techniques and thus for strengthening the scientific evidence base for clinical decision making. Studies to date have used a one-time stimulation (i.e., magnitude production) paradigm. Bearing in mind that stimulation and training paradigms represent different phases of treatment efficacy research (Yorkston et al., 2007), these comparative studies suggest that both clear speech and an increased vocal intensity yield similar magnitudes of improvement in sentence intelligibility for speakers with mild dysarthria (see Stipanec et al., 2016). Clear speech or an increased vocal intensity also enhance vowel segmental articulation, with clear speech yielding the most robust effects (Tjaden, Lam, & Wilding, 2013). The

Table 3. Descriptive statistics for first moments (M1) in the form of means and standard deviations are reported for /s/ and /ʃ/ as a function of group, condition, and position.

Group	M1 _{/s/} (kHz)						M1 _{/ʃ/} (kHz)					
	Habitual		Clear		Loud		Habitual		Clear		Loud	
	Initial	Medial	Initial	Medial	Initial	Medial	Initial	Medial	Initial	Medial	Initial	Medial
Control	6.186 (1.102)	5.840 (0.953)	6.586 (0.999)	6.295 (1.055)	6.607 (1.239)	6.404 (1.038)	4.378 (0.720)	4.461 (0.806)	4.461 (0.635)	4.479 (0.696)	4.874 (0.611)	4.756 (0.704)
MS	6.388 (0.824)	6.110 (0.901)	6.631 (0.977)	5.597 (.810)	6.648 (0.953)	6.450 (1.087)	4.699 (0.711)	4.511 (0.848)	4.595 (0.641)	4.633 (0.731)	4.782 (0.751)	4.907 (0.793)
PD	6.081 (0.946)	5.824 (0.871)	6.206 (0.892)	6.160 (0.893)	6.242 (0.945)	5.928 (1.101)	4.537 (0.786)	4.557 (0.709)	4.504 (0.724)	4.510 (0.631)	4.599 (0.623)	4.757 (0.663)

Note. MS = multiple sclerosis; PD = Parkinson's disease.

Figure 1. First moment difference (M1Diff; kHz) measures for pairs of stops and fricatives is reported as a function of group, condition, and position. Error bars represent standard deviations. CT = control; PD = Parkinson's disease; MS = multiple sclerosis.

present study extends this line of inquiry to consonant segmental production. The remainder of the discussion considers the effects of condition and position on M1. Findings for higher moments also are briefly considered, as are limitations.

Speaking Condition Effects on M1

Evidence of stimulability for a dysarthria treatment technique is desirable prior to embarking upon a time-intensive, costly training paradigm (Yorkston et al., 2010).

Table 4. Results of the statistical analyses of M2, M3, and M4 for the stops and the fricatives for each group in habitual, clear, and loud speaking conditions.

Group	Stops						Fricatives					
	M2		M3		M4		M2		M3		M4	
	/t/	/k/	/t/	/k/	/t/	/k/	/s/	/ʃ/	/s/	/ʃ/	/s/	/ʃ/
Condition			*		*		*		*	*	*	
Position			L<C<H		C<L<H		C<L<H		C=L<H	L<C=H	C=L<H	*
Group × Condition												
Group × Position												
Group × Condition × Position												

Note. M2 = second spectral moment (standard deviation); M3 = third spectral moment (skewness); M4 = fourth spectral moment (kurtosis); L = loud condition; C = clear condition; H = habitual condition; M = medial; I = initial.

* $p \leq .05$.

Figure 2. First moment (M1) time histories for fricatives are plotted as a function of group and condition. CT = control; PD = Parkinson's disease; MS = multiple sclerosis.

The fact that the magnitude production paradigm elicited the expected adjustments in articulation rate and vocal intensity for clear and loud, albeit in a curtailed manner for disordered speaker groups relative to controls, as initially reported in our vowel acoustics study (Tjaden, Lam, & Wilding, 2013), which also included the 37 speakers in the present study, is therefore significant. Empirical evidence of stimulability for clear speech is particularly important, because these studies suggest the feasibility of investigating clear speech training paradigms in PD and MS. In our prior vowel acoustics study, the clear condition had a greater impact than the loud condition on static measures

of vowel spectra, as indexed by an increase in peripheral and nonperipheral vowel space areas. In contrast, in the current study, the loud condition had a stronger and more consistent impact on measures of consonant spectra. Lingualveolar /t/ and /s/ as well as linguapalatal /ʃ/ were associated with a higher M1 for loud relative to habitual and even clear, in some instances. This result may reflect the effect of an increase in source level on M1 due to increased energy at higher frequencies (Shadle & Mair, 1996). Changes in M1 also may be related to adjustments in filter characteristics. For example, an increase in M1 could reflect a more anterior constriction position or in the case of fricatives, a narrower

Table 5. R^2 and p values of the linear regressions estimated for the time-course analyses for both fricatives for each group in habitual, clear, and loud speaking conditions.

Group	/s/						/ʃ/					
	Habitual		Clear		Loud		Habitual		Clear		Loud	
	R^2	p value	R^2	p value	R^2	p value	R^2	p value	R^2	p value	R^2	p value
Control	.195	.273	.004	.888	.164	.319	.727	.007*	.333	.134	.594	.025*
MS	.559	.033*	.072	.519	.149	.344	.753	.005*	.726	.007*	.745	.006*
PD	.586	.027*	.002	.916	.199	.268	.648	.016*	.412	.086	.612	.022*

Note. MS = multiple sclerosis; PD = Parkinson's disease.

* $p < .05$.

constriction. A higher M1 for /f/ also could reflect reduced lip rounding. The only consonant for which M1 was significantly different for clear and habitual was /t/, with the direction of the effect suggesting a more anterior constriction for clear (see Maniwa et al., 2009).

The suggestion that global dysarthria treatment techniques may differentially have an impact on speech behaviors (i.e., consonants versus vowels, segmentals versus suprasegmentals) is not new. A previous comparative study reported that an increased vocal intensity enhanced consonant segmental production in dysarthria, while rate reduction enhanced vowel segmental production (Tjaden & Wilding, 2004). As an aside, clear speech was not included in the 2004 study, which was based on an entirely different set of speakers, and rate reduction was not of interest in the present study owing to research suggesting that this treatment technique does not significantly benefit intelligibility (Tjaden, Richards, et al., 2013; Van Nuffelen et al., 2010). Studies investigating multiple cues or instructions for implementing global treatment techniques also report variations in speech behaviors as a function of the cue (Darling & Huber, 2011; Lam & Tjaden, 2016; Van Nuffelen et al., 2010). Why an increased intensity would have the greatest effect on consonant spectra while clear speech would have the greatest effect on vowel spectra is not wholly apparent but presumably indicates a stronger impact of source (i.e., increased vocal intensity for loud and to a lesser extent clear) on consonant spectra. An ongoing challenge for dysarthria research is to provide a comprehensive account of how global techniques have an impact on an array of speech behaviors, as well as how these techniques have an impact on metrics at the activity and participation levels of the ICF. This challenge should not be underestimated given the focus advanced treatment research designs place on identification of a single outcome variable.

Despite the fact that loud and in one instance clear was associated with a significant change in M1, neither therapeutic technique enhanced spectral contrast for pairs of stops or fricatives, as indexed by M1 difference measures. Wenke et al. (2010) reported similar results for speakers with nonprogressive dysarthria following LSVT. Prior stimulation studies of dysarthria investigating clear speech or an increased vocal intensity also have reported an enhanced M1 difference for stops but not fricatives (Lam & Tjaden, 2016; Tjaden & Wilding, 2004). In contrast, a study of neurotypical talkers reported a robust increase in spectral contrast for pairs of clear versus conversational fricatives (Maniwa et al., 2009). Speech stimuli in Maniwa et al. (2009) were composed of nonsense vowel–consonant–vowel syllables, however, whereas the dysarthria studies reporting null or mixed findings examined word-initial consonants in sentences. In addition, the dysarthria studies investigating clear speech used stimulation, while Maniwa et al. (2009) used an interface intended to elicit specific phonetic contrasts from speakers in response to misperceptions by a simulated listener. As discussed below, the fact that dysarthria research has primarily studied individuals with mild to moderate speech impairment also

may help to explain negative or mixed results for M1 difference.

Clinical perceptual metrics of sentence intelligibility and perceived speech severity for speakers with MS or PD in the present study indicated relatively mild dysarthria, and this may help to explain the lack of group differences in consonant spectral measures. Alternatively, the lack of group differences could indicate that disordered speakers were spontaneously adopting a style of speaking characterized by high consonant articulatory–acoustic specification as a means of compensating for other speech production deficits, such as deficits in vowel production or prosody (Goberman & Elmer, 2005). Given group differences in vowel acoustics reported in other studies, it also might be speculated that the moments-based analyses lacked sensitivity. However, spectral moments have been shown to reveal differences in consonant production for healthy talkers and other forms of dysarthria (e.g., Kim, Kent, & Weismer, 2011). Nonetheless, the application of moments-based analyses to the connected speech of even mild dysarthria is not without challenges. Automated metrics being developed may ultimately prove to be superior (Koenig et al., 2013).

Finally, neurotypical speakers produce fricatives with time-varying change in M1 (e.g., Iskarous et al., 2011; Koenig et al., 2013; Munson, 2004), but dynamic characteristics of consonant spectra have received limited attention in dysarthria (see Tjaden & Turner, 1997). The exploratory analysis indicated that M1 time histories for all groups had a concave shape characterized by a sharp lowering at the final time point reflecting the influence of the upcoming vowel. Interestingly, when the data point at the fricative + vowel boundary was disregarded, there were several instances in which the clear and loud conditions enhanced the linearity of M1 time histories—particularly for the MS and PD groups. The extent to which this enhanced linearity might reflect increased stability or specification in the speech production mechanism requires further study, as does the perceptual relevance, if any, of dynamic, consonant, spectral change. Future studies also may wish to evaluate alternative metrics for quantifying the time course of spectral variability for fricatives (e.g., Koenig et al., 2013; Munson, 2004).

Position Effects on M1

Prior dysarthria studies investigating spectral properties of consonants have examined word-initial consonants, following Forrest et al. (1988). Thus, the present study represents an initial effort to investigate spectral properties of consonants in multiple word positions produced by speakers with dysarthria. M1 values typically differed for consonants in the word-initial and word-medial positions. In the initial position, M1 was higher for the anterior consonants (/s/ and /t/) and lower for the posterior stop (/k/), as would be expected on the basis of domain initial articulatory strengthening (Cho, 2015). M1 difference measures for pairs of stops and fricatives also indicated enhanced spectral contrast at word

onset for all groups. To the extent that listeners first try to use a lexically based speech segmentation strategy, the increased spectral contrast among consonants in the word-initial position could conceivably assist listeners in parsing the acoustic speech stream (see Liss, 2007). Interestingly, a higher order interaction suggested that the clear condition yielded similar M1 difference measures for word-initial and word-medial fricatives produced by the PD group and to some extent the control group. A tempering of spectral contrast in the context of a dysarthria therapy technique would seem undesirable, but additional research is needed before drawing strong conclusions.

Higher Moment Coefficients

Since the publication of Forrest et al. (1988), the majority of studies investigating spectral properties of consonants have focused on M1 or a related spectral center of gravity measure. This likely is due to the fact that the various speech production behaviors potentially influencing M1 are reasonably well understood. Moreover, Forrest et al. (1988) found that M2 was not useful for classifying voiceless obstruents, M3 tends to be inversely related and thus redundant with M1, and M4 has been rarely reported (Koenig et al., 2013). The current results provide evidence of redundancy for M1 and M3. For both M1 and M3, the main effect of condition was significant for /t/, /s/, and /f/, with M1 highest and M3 lowest in the habitual condition. The fact that there were no marked differences in the pattern of results for higher moment coefficients versus those for M1, particularly in the form of group differences, supports the focus on M1 here and in other dysarthria studies.

Limitations and Conclusions

Even though results for articulation rate and vocal intensity indicated that the clear and loud conditions were effectively implemented, results for a stimulation paradigm might not be identical to those for trained loud or clear speech. Acoustic measures also were obtained for speech materials that were read aloud, which is an unusual speaking task. However, reading aloud is commonly used in speech research because reading permits precise control of segmental and suprasegmental context, which is a requirement in studies such as the one conducted here. In addition, real words were studied, as opposed to nonwords in carrier sentences. Although real words increase ecological validity, this choice may have obscured some subtle acoustic-phonetic effects that could have emerged with stricter phonetic environments. The number of consonant tokens available also was limited.

Finally, moment coefficients were used to quantify consonant spectra. These measures have been used in prior studies of dysarthria and normal speech and are desirable because they can be obtained automatically using speech acoustics software. The sensitivity of moment coefficients to very subtle articulatory differences or changes that may

accompany mild dysarthria remains uncertain. Koenig et al. (2013) recently suggested a new set of measures for quantifying spectral properties of /s/. An advantage of these measures is that they afford a more straightforward interpretation of source versus filter effects on consonant spectra. Whether these measures can be applied to obstruents in addition to /s/ as well as clinical populations such as dysarthria remains to be determined.

In conclusion, the loud and especially clear conditions yielded subtle changes in consonant spectra that were generally similar for all speaker groups. These conditions also did not enhance consonant spectral contrast. The robust effect of word position on consonant spectra for all groups suggests that the construct of domain-initial articulatory strengthening extends to mild dysarthria (Cho, 2015) and supports the idea that persons with mild dysarthria secondary to PD and MS vary consonant production along a hyper-hypo continuum. Future studies are needed to investigate how or whether consonant production bears on the improved intelligibility previously reported for these global dysarthria treatment techniques.

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