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# Speech and Pause Characteristics Associated with Voluntary Rate Reduction in Parkinson's disease and Multiple Sclerosis

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## Abstract

The primary purpose of this study was to investigate how speakers with Parkinson's disease (PD) and Multiple Sclerosis (MS) accomplish voluntary reductions in speech rate. A group of talkers with no history of neurological disease was included for comparison. This study was motivated by the idea that knowledge of how speakers with dysarthria voluntarily accomplish a reduced speech rate would contribute toward a descriptive model of speaking rate change in dysarthria. Such a model has the potential to assist in identifying rate control strategies to receive focus in clinical treatment programs and also would advance understanding of global speech timing in dysarthria. All speakers read a passage in Habitual and Slow conditions. Speech rate, articulation rate, pause duration, and pause frequency were measured. All speaker groups adjusted articulation time as well as pause time to reduce overall speech rate. Group differences in how voluntary rate reduction was accomplished were primarily one of quantity or degree. Overall, a slower-than-normal rate was associated with a reduced articulation rate, shorter speech runs that included fewer syllables, and longer more frequent pauses. Taken together, these results suggest that existing skills or strategies used by patients should be emphasized in dysarthria training programs focusing on rate reduction. Results further suggest that a model of voluntary speech rate reduction based on neurologically normal speech shows promise as being applicable for mild to moderate dysarthria.

## 1. Introduction

Speech rate is a measure of the amount of speech produced per unit time and typically is expressed in units such as words per minute or syllables per second. Articulation time and pause time are the components of speech rate. Articulation time refers to the time spent producing speech segments or phonetic events. Dividing the number of syllables produced by articulation time in seconds yields articulatory rate in syllables per second (syll/sec). Pause time refers to the accumulation of pause duration over the course of a given speech sample while the term pause frequency refers to the number of pauses in a speech sample.



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Thus, speaking rate may be altered by changing articulation time, changing pause time or changing both articulation and pause time.

Rate control, in the form of a slower-than-typical rate, has long been used as a clinical technique for improving intelligibility in dysarthria (Yorkston, Hakel, Beukelman & Fager, 2007). Not all speakers with dysarthria exhibit improved speech intelligibility when using a slower-than-typical rate, however (Dagenais, Southwood, & Lee, 1998; Tjaden & Wilding, 2004; Turner, Tjaden & Weismer, 1995; Van Nuffelen, De Bodt, Wuyts, & Van de Heyning, 2009; Van Nuffelen, De Bodt, Vanderwegen, Van de Heyning, Wuyts, 2010). For example, Van Nuffelen et al. (2010) reported that approximately 50% of 27 speakers with various neurological diagnoses and dysarthrias exhibited a meaningful improvement in scaled intelligibility when using rate reduction methods. Relatedly, Turner et al. (1995) reported that five of nine speakers with dysarthria secondary to Amyotrophic Lateral Sclerosis (ALS) demonstrated at least some degree of improvement in scaled intelligibility when using a slower-than-typical rate. Factors predicting those individuals who will benefit from therapeutic techniques aimed at reducing speech rate are poorly understood, although Van Nuffelen et al. (2010) concluded that type of dysarthria, habitual speaking rate, and overall speech severity did not differentiate individuals who did and did not experience improved intelligibility when using rate reduction. In the absence of strong empirical data to guide clinical decisions as to whether a given individual will benefit from rate control, trial and error therapy is the recommended to determine candidacy for rate control (Van Nuffelen et al., 2010).

Development of a descriptive model of speaking rate change in dysarthria has been suggested as a mechanism that may assist in determining candidacy for rate control (Turner & Weismer, 1993). That is, because rate manipulation can be accomplished in a variety of ways, an understanding of how speakers with various neurological diagnoses and dysarthria voluntarily adjust speech time and pause time to alter speech rate may ultimately aid in identifying a rate control strategy (i.e., saying fewer syllables per breath group, using longer pauses, pausing more frequently) that capitalizes on a speaker's extant strengths. Such an approach also would help to identify any deviant or maladaptive characteristics associated with rate control requiring attention in rate reduction training. For example, pauses occurring at unexpected or atypical locations, such as in the middle of a phrase or clause, have the potential to adversely affect listeners' ability to use syntactic predictions for lexical access and lexical segmentation (see review in Liss, 2007).

Typical or habitual speech rate characteristics for persons with a variety of neurological diseases and dysarthrias have been widely reported (e.g., Ball, Beukelman, & Pattee, 2002; Goberman & Elmer, 2005; Huber & Darling, 2011; Nishio & Niimi, 2001; Schulz, Greer & Friedman, 2004). Still other studies have shown that speakers with dysarthria can voluntarily reduce overall articulation rate for sentence-level material or a reading passage (Lowit, Brendel, Dobinson & Howell, 2006; McRae, Tjaden & Schoonings, 2002; Turner & Weismer, 1993). However, as discussed in the following section, knowledge of how speakers with dysarthria voluntarily adjust pause location, pause time, and articulation time to accomplish an overall reduced speech rate is incomplete. Studies investigating voluntary rate reduction are important because this rate control technique most closely approximates the broader goal of nonprosthetic rate control methods – that of adopting a new speaking rate that differs from habitual. Stated differently, speaking slower on demand is a more naturalistic rate control method as compared to assisted techniques like delayed auditory feedback, alphabet supplementation or pacing board (Van Nuffelen et al., 2010).

Turner and Weismer (1993) conducted the first in-depth study investigating how speakers with dysarthria adjust articulation time and pause time to voluntarily reduce speaking rate.

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Nine speakers with dysarthria secondary to ALS and a group of healthy control talkers read a passage in Habitual, Fast, and Slow speaking conditions. Voluntary rate manipulation was stimulated using a magnitude production paradigm. Conclusions concerning rate reduction per se are hindered by the fact that articulation and pause measures were generally collapsed across Habitual, Fast, and Slow speaking conditions for the majority of data analyses. Pause placement also was not of interest in this study. Nonetheless, Turner and Weismer (1993) interpreted their findings to suggest that speakers with ALS altered articulation rate and pause duration to achieve speaking rate change in much the same manner as neurologically normal speakers.

Hammen and Yorkston (1996) subsequently reported speech and pause characteristics for a reading passage produced by six speakers with hypokinetic dysarthria secondary to Parkinson's disease (PD) and six healthy control talkers. Although rate reduction was elicited using computerized pacing software and results likely do not directly translate to voluntary rate manipulation, Hammen and Yorkston's (1996) investigation appears to be the only published, group study reporting the effects of rate reduction on pause placement characteristics in dysarthria. Results indicated that both speaker groups used articulation time and pause time to reduce speech rate. Both speaker groups also relied more heavily on pause duration, as compared to articulation time, to achieve changes in overall speech rate. Finally, speakers with PD had a greater proportion of syntactically inappropriate pauses when using a typical or habitual speech rate as compared to controls, and rate reduction resulted in a further increase in the proportion of syntactically inappropriate pauses. As previously noted, pauses occurring at inappropriate grammatical locations may have adverse perceptual consequences. In fact, Hammen and Yorkston (1996) recommended incorporating explicit cues for pause placement when using pacing software to reduce speech rate in dysarthria.

Most recently, Van Nuffelen et al., (2010) investigated how a variety of rate control methods impact speech and pause characteristics for reading passages produced by 27 speakers with a variety of neurological diagnoses and dysarthrias. The different rate control methods had varied effects on speech and pause characteristics. For example, delayed auditory feedback was found to mostly impact articulation time, while other techniques such as pacing board affected both articulation time and pause time. Interestingly, magnitude production or speaking slower on demand failed to elicit a significant reduction in speaking rate or articulation rate. This result differs from studies reporting that speakers with dysarthria can voluntarily reduce articulation rate and speaking rate, and thus warrants further study (Kleinow, Smith & Ramig, 2001; Lowit et al., 2006; McHenry, 2003; McRae et al., 2004; Tjaden & Wilding, 2004). Of note, published studies to date investigating voluntary rate reduction in dysarthria are generally limited to measures of overall speech or articulation rate. Pause characteristics are not routinely reported.

In summary, knowledge of how speakers with a variety of neurological diagnoses and dysarthrias voluntarily accomplish a reduced speech rate would contribute toward development of a descriptive model of speaking rate change in dysarthria. In addition to advancing understanding of global speech timing in dysarthria, such a model has the potential to assist in identifying rate control strategies to receive focus in clinical treatment programs. Present understanding of how speakers with dysarthria voluntarily adjust pause location, pause time, and articulation time to accomplish a reduced speech rate is far from complete. Thus, the primary purpose of the current study was to further investigate the means by which speakers with dysarthria secondary to PD and Multiple Sclerosis (MS) reduce speech rate. A group of control talkers with no history of neurological disease was included for comparison. The current study expands upon previous studies investigating voluntary rate manipulation in dysarthria in several respects. First, the present study reports how voluntary rate reduction impacts the grammatical placement of pauses. Articulation time and pause characteristics associated with voluntary rate manipulation also are quantitatively compared for two disordered speaker groups.

# 2. Methods

## 2.1. Participants

A total of 44 speakers were studied. The MS group included seven men and 10 women ranging in age from 25 to 60 years (Mean age = 49 years; SD= 10), the PD group was comprised of six men and six women ranging in age from 42 to 81 years (Mean age= 63 years; SD= 12), and the Control group was comprised of seven men and eight women ranging in age from 20 to 77 years (Mean age= 56; SD= 14). These participants are part of a larger, ongoing project investigating acoustic and perceptual consequences of behavioral treatment techniques for dysarthria. Articulatory rate data have been reported previously for these speakers (Tjaden & Wilding, 2004; 2011). However, these earlier studies focused on segmental and fundamental frequency adjustments associated with a slower-than-typical rate, and were not intended to provide an in-depth analysis of speaking rate characteristics. Participant characteristics are briefly reviewed in the following section. Additional details may be found in previous studies (Tjaden & Wilding, 2004; 2011).

All participants underwent cognitive and puretone audiometric screening. Control speakers reported no history of neurological disease or speech-language therapy. Participants with MS and PD were taking a variety of symptomatic medications, but had not received surgical treatment for their disease. Tables 1 and 2 summarize participant characteristics for speakers with MS and PD, respectively. Dysarthria diagnoses, perceptual characteristics, and impressions of overall severity reflect the consensus judgment of three speech-language pathologists (SLPs). These judgments were based on audio-recordings of a standard clinical speech sample comprised of vowel prolongation, diadochokinesis, the Grandfather Passage (Duffy, 2005) and a brief extemporaneous monologue.

Five graduate students in speech-language pathology provided the scaled estimates of intelligibility for the Grandfather Passage reported in Tables 1 and 2 using a fixed modulus magnitude-estimation paradigm. Scale values represent the geometric mean for the five listeners. These scaled estimates of intelligibility were obtained to provide a metric of overall speech severity, in lieu of the fact that a published intelligibility test was not administered. Higher scale values in Tables 1 and 2 indicate relatively better intelligibility. Intelligibility could not be scaled for PDF2 owing to technical difficulties.

## 2.2. Speech Sample and Recording Procedures

Participants were audio-recorded in a sound-treated room while reading the John Passage (Tjaden & Wilding, 2004). This 192-word passage was developed to include a variety of phonetic events. The majority of words (76%) contain one syllable. The acoustic signal was transduced using a high quality head-mounted microphone (AKG C410) and was digitized at a sampling rate of 22 kHz directly to computer hard disk. A magnitude production paradigm was used to elicit variations in rate, with all speakers initially reading the passage in the Habitual condition. The Slow condition was operationally defined as a rate half as fast as typical or habitual. Data collection for speakers with PD took place approximately one hour after ingestion of anti-Parkinonian medications, while data collection for participants with MS took place when individuals reportedly were well rested.

## 2.3. Acoustic Analyses

Articulatory rate was measured for each speech run using the combined waveform and wideband (bandwidth setting of 300–350 Hz) digital spectrographic displays of TF32 (Milenkovic, 2002). A run was operationally defined as a stretch of speech bounded by silent periods between words of at least 200 ms (Turner & Weismer, 1993). Conventional acoustic criteria were used to identify run onsets and offsets, such as stop release bursts, frication, or voicing energy. The printed script of the reading passage was used to determine syllable counts (see also Yunusova, Weismer, Kent & Rusche, 2005). If speakers produced extra words or syllables, these were included in the syllable counts. For each speaker and condition, a variety of measures were obtained for each speech run including duration (ms), length (number of syllables), and articulatory rate (syllables/second). For each speaker and condition, acoustic measures were averaged across runs to yield an average run duration, run length, and articulatory rate. Pause characteristics of interest included the total number of pauses, average pause duration (ms), and percentage of grammatically appropriate pauses. A grammatically appropriate pause was operationally defined as a pause occurring between clauses or phrases (Hammen & Yorkston, 1996; Henderson, Goldman-Eisler & Skarbek, 1966). Finally, speaking rate (syllables/second) and speech/pause ratios were calculated for each speaker and condition. Speaking rate was calculated by tabulating the total number of syllables for the entire passage and dividing by the total passage reading time. Speech/pause ratios were defined as the proportion of passage reading time devoted to articulation time. These ratios were of interest given previous studies suggesting that these ratios may be a more sensitive measure of mild to moderate dysarthria, as was typical of most speakers with MS and PD in the present study (see Tables 1 and 2), as compared to global timing measures such as articulatory or speech rate (Nishio & Niimi, 2001; Lowit et al., 2006).

**2.3.1 Reliability of Acoustic Measures—**For each speaker and condition, acoustic measures were repeated for approximately 10% of speech runs (run duration) and pauses. Pearson product correlations and measures of average, absolute measurement error were used to index reliability. Binary judgments (i.e., 0 = not appropriate; 1 = appropriate) concerning grammatical appropriateness of pauses also were repeated for 10% of pauses for each speaker and condition. Correlations were used to index reliability for judgments of pause grammaticality.

Intrajudge reliability for pause duration yielded an average measurement error of 16 ms (SD=47 ms) and a correlation of .99. Judgments regarding grammatical appropriateness of pauses were highly repeatable, as indicated by a correlation of 1.0. Intrajudge reliability for run duration yielded an average measurement error of 10 ms (SD=40 ms) and a correlation of .99.

Interjudge reliability for pause duration yielded an average, absolute measurement error of 16 ms (SD=25 ms). Judgments concerning the grammatical appropriateness of pauses were strongly correlated (r=.98).

Interjudge reliability for run duration yielded an average measurement error of 22 ms (SD=62 ms) and a correlation of .99.

## 2.4. Data Analyses

Both descriptive (i.e., mean, standard deviation) and parametric statistics were employed. For parametric analyses, a mixed linear model was fit to dependent variables in this repeated measures design. The model was based on an unstructured covariance structure, allowing for unequal variances in each group and unequal correlations between groups. The model included main effects of Condition (Habitual, Slow), Group (MS, PD, Control), and a Group

× Condition interaction. To control for different proportions of men and women in the three speaker groups, a variable representing gender was included as a covariate in all of the analyses. A nominal alpha level of .05 was used to ascertain statistical significance of omnibus tests. For completeness, all possible post hoc pairwise comparisons were performed using Tukey-Kramer tests, regardless of outcomes for omnibus tests. Bonferroni adjusted p-values were used to determine statistical significance of post hoc tests ($p<.05$). All statistical tests were carried out using SAS version 9.1.3 statistical software (Cary, NC).

## 3. Results

Table 3 reports average numbers of speech runs. By definition, all runs were followed by a pause, with the exception of passage-final runs. Speech run counts therefore are synonymous with pause counts or pause frequency. The average number of syllables produced per speech run also is reported. Table 3 suggests more runs, and thus more pauses for the Slow condition as compared to Habitual. This was confirmed by a significant main effect of Condition ($F(1, 40)=44.30$; $p<.0001$) in the statistical analysis. The main effect of Group and the Group × Condition interaction were not significant. Post hoc analyses further indicated that the Control and PD groups, but not the MS group, produced significantly more runs - and thus pauses - in the Slow condition as compared to Habitual ($p<.0001$).

Table 3 also suggests that all speaker groups produced fewer syllables per run, on average, for the Slow condition. This observation was confirmed by a significant main effect of Condition ($F(1, 40)=57.96$; $p<.001$) in the statistical analysis. The main effect of Group and the Group × Condition interaction were not significant. For all groups, post hoc analyses indicated that speech runs in the Slow condition contained fewer syllables, on average, as compared to the Habitual condition ($p<.02$).

Figure 1 reports average articulatory (upper panel) and speaking (lower panel) rates as well as standard deviations. To review, articulatory rate is a measure that derives solely from the time devoted to producing speech segments or phonetic events (i.e., time spent articulating) while speaking rate derives from the time spent articulating as well as pausing. Statistical analysis of the articulatory rate data revealed a significant main effect of Condition ($F (1, 40) =144.22$; $p<.0001$) and a significant Group × Condition interaction ($F (2, 40) =6.06$; $p=.005$). The main effect of Group was not significant. For all groups, post hoc analyses indicated that articulatory rate was significantly reduced in the Slow condition ($p<.00017$). On average, the PD group reduced articulatory rate in the Slow condition by 18% (SD=12%), the MS group reduced articulatory rate by 24% (SD=15%) and the Control group reduced articulatory rate by 35% (SD=11%) The Group × Condition interaction was attributable to subtle differences in the patterning or ordering of articulatory rates for the three speaker groups in the Habitual versus Slow conditions, as illustrated in the upper panel of Figure 1. For example, average articulatory rate in the Habitual condition was fastest for the Control group, followed by the PD and MS groups. In contrast, average articulatory rate in the Slow condition was fastest for the PD group, followed by the MS and Control groups. Importantly, within both the Habitual and Slow speaking condition, there was no significant difference in articulatory rates for all possible pairs of speaker groups.

Statistical analysis of speaking rate data also revealed a significant main effect of Condition ($F (1, 40) =178.41$; $p<.0001$) as well as a significant Group × Condition interaction ($F (2, 40) =5.59$; $p=.0072$). The main effect of Group was not significant. Post hoc analyses indicated that for all groups, speaking rate was reduced in the Slow condition ($p<.00002$). On average, the PD group reduced speech rate by 25% (SD=17%), the MS group reduced speech rate by 34% (SD=16%) and the Control group reduced speech rate by 44% (SD=9%). As for measures of average articulatory rate, the Group × Condition interaction was attributable to differences in the relative ordering of speaking rates across groups in the habitual versus slow conditions, as illustrated in the lower panel of Figure 1. Within both the Habitual and Slow conditions, post hoc comparisons failed to reveal significant difference in speaking rate for all possible pairs of speaker groups.

Figure 2 reports average pause durations and standard deviations (upper panel) as well as average run durations and standard deviations (lower panel). The statistical analyses indicated main effects of Group ($F$ (2, 40) =6.14; $p$=.0047) and Condition ($F$ (1, 40) =23.95; $p$<.0001) but no Group × Condition interaction. As suggested in the upper panel of Figure 2, post hoc testing indicated longer average pause durations for the PD group compared to Controls for both the Habitual and Slow conditions ($p$<.03) and longer pauses for the PD group compared to the MS group for the Slow condition (p=.04). The MS and PD groups also significantly lengthened average pause duration for the Slow condition ($p$<.011). Average pause durations for the Control group were not significantly different for the Habitual and Slow conditions, however. Statistical analysis of average run durations shown in the lower panel of Figure 2 indicated shorter runs in the Slow condition, as indicated by a significant main effect of Condition ($F$(1, 40)=24.75; $p$<.0001). The main effect of Group and the Group × Condition interaction were not significant. Post hoc testing indicated shorter average run durations in the Slow condition for the Control and MS groups ($p$<.006), but not the PD group.

Figure 3 reports the proportion of grammatically appropriate pauses. Visual inspection of this Figure suggests that on average, about 80% of pauses produced by the MS and PD groups in the Habitual condition were grammatically appropriate as compared to about 95% of pauses for Controls. Similarly, about 75% of pauses for the MS and PD groups in the Slow condition were grammatically appropriate, as compared to about 80% of pauses for Controls. Statistical analyses indicated significant main effects of Group ($F$ (2, 40) =4.03; $p$<.025) and Condition ($F$ (1, 40) =17.86; $p$=.0001), but no Group × Condition interaction. Post hoc testing indicated a reduced proportion of grammatically appropriate pauses in the Habitual condition for the MS group versus Controls ($p$=*.008*), with the PD-Control comparison approaching significance ($p$=.059). Finally, the Slow condition was associated with a reduction in the proportion of grammatically appropriate pauses for the Control group ($p$=.002).

Average speech/pause ratios are reported in Figure 4. As previously reviewed, these types of ratios reflect the proportion of the reading passage devoted to articulation versus pause time. A ratio of .5 would indicate that the reading passage was equally comprised of articulation time and pause time. Ratios greater than .5 indicate that a relatively larger proportion of the reading passage was devoted to articulation time as compared to pause time. All of the average ratios reported in Figure 4 are greater than .5, indicating that a greater proportion of reading passages for all groups and speaking conditions were devoted to articulation time. The statistical analysis indicated significant main effects of Group ($F$ (2, 40) =4.90; $p$=.013) and Condition ($F$ (1, 40) =60.13; $p$<.0001), but no Group × Condition interaction. Post hoc analyses further indicated that all speaker groups reduced the proportion of articulation time and thus, increased the proportion of pause time in the Slow condition, as indexed by smaller speech-pause ratios ($p$<.002). In addition, in the Habitual condition, speech-pause ratios for the PD group were significantly smaller than for Controls - indicating a relatively greater proportion of pause time for the PD group's Habitual reading passage ($p$=.011).

Finally, Figure 5 illustrates the relationship between run duration (ms) and the number of syllables per run. The upper panel reports data for the Habitual condition, and the lower panel reports data for the Slow condition. Linear regression functions have been fit to each group's data. For all groups and conditions, Figure 5 suggests a strong linear relationship between run duration and the number of syllables per run. For the Habitual condition, the relationship was most robust for the Control group (adjusted $r^2$=.92) followed by the MS (adjusted $r^2$=.84) and PD (adjusted $r^2$=.81) groups. For the Slow condition, the strength of the relationship was slightly reduced for the Control group (adjusted $r^2$ =.83). Rate reduction tended to have relatively less impact on the strength of the relationship between run length and number of syllables per run for disordered speaker groups (MS adjusted $r^2$=.84; PD adjusted $r^2$=.78).

## 4. Discussion

The present study extends our understanding of how speakers with mostly mild to moderate dysarthria secondary to PD or MS voluntarily adjust articulation and pause characteristics to reduce speaking rate for a reading passage. Results also advance understanding of the extent to which rate reduction strategies used by speakers with MS and PD resemble those of neurologically normal talkers. Finally, the current study adds to existing studies reporting habitual or typical speech rate characteristics in dysarthria. Major findings and implications are considered in the following sections.

### 4.1. Manipulation of Articulation Time and Pausing to Accomplish Speaking Rate Reduction

All speaker groups were able to significantly reduce speech rate for the reading passage (lower panel Figure 1). The magnitude of the rate reduction varied from an average low of 25% for the PD group to an average high of 44% for the Control group. In contrast, Van Nuffelen et al.'s (2010) "speaking slower on demand" condition did not elicit a meaningful reduction in speech rate for talkers with a variety of dysarthrias and neurological diagnoses. In fact, participants in Van Nuffelen et al.'s (2010) study only reduced speech rate by an average of 9% for a reading passage. The current results are not unique, however. Other studies have found that individuals with a variety of dysarthrias, neurological diagnoses, and overall speech severity can voluntarily reduce speech rate for sentences or a reading passage (McHenry, 2003; Turner & Weismer, 1993). These studies as well as the present investigation report data for speakers of American-English, while Van Nuffelen's (2010) study was conducted in Belgium. Language or cultural influences as well as cross-study differences in the amount or type of modeling and feedback during training may help to explain the different results. Future investigations are needed to explore these issues.

Differences in how the various speaker groups adjusted articulation and pause characteristics to accomplish the reduced speech rate were mostly one of quantity or degree. For example, all groups reduced articulation rate for the Slow condition (upper panel of Figure 1), although the magnitude of the reduction varied. The Control group reduced articulation rate the most (mean = 35%) followed by the MS (mean =24%) and PD groups (mean =18%). The tendency for speakers with dysarthria to reduce articulation rate proportionately less than healthy talkers within the context of a voluntary rate reduction paradigm has been reported previously in studies investigating individuals with a variety of neurological diagnoses and dysarthrias (Kleinow et al., 2001; Lowit et al., 2006; McHenry, 2003; Turner & Weismer, 1993). Interestingly, despite the fact that there were no group differences in speech or articulation rate within the Habitual or Slow conditions (Figure 1), the MS and PD groups reduced speech rate proportionately less than control talkers. This finding raises the possibility that a reduced ability to voluntary slow global speech timing might serve as a general, clinical marker of mild to moderate dysarthria. On the other hand, McRae et al. (2002) found no difference in the extent of articulatory rate reduction for a reading passage produced by speakers with PD and healthy controls, and speech materials in the McHenry (2003) and Kleinow et al. (2001) studies consisted solely of the laboratory sentence "Buy Bobby a puppy." Additional studies therefore would help to evaluate the suggestion that extent or magnitude of rate reduction might prove useful as a clinical marker of dysarthria. Whether speakers with dysarthria are able to maintain a reduced rate over a lengthy speech sample or spontaneous communicative exchange as well as the extent to which a reduced rate can be maintained beyond a single training session also requires further study.

The manner in which the reduced articulation rate in the Slow condition was accomplished was similar for all speaker groups. For example, on average, all groups used shorter runs containing fewer syllables in the Slow condition, although the reduction in average run duration for the PD group's Slow condition was not statistically significant (see lower panel of Figure 2). To the extent that clinical dysarthria training programs focus on voluntary rate reduction, these results suggest that the emphasis should be on training shorter speech runs or phrases comprised of fewer syllables. Such a focus would capitalize on existing skills or strategies for rate reduction used by speakers with dysarthria. The fact that all groups tended to slow articulation rate by using shorter runs containing fewer syllables further suggests that a descriptive model of articulatory rate reduction based on neurologically normal speech shows promise as being broadly applicable to mild to moderate dysarthria. This suggestion also is supported by the regression analysis indicating that the form of the relationship between run duration and number of syllables per run length was similar for all speaker groups (Figure 5).

Rate reduction also was associated with changes in pause characteristics. Both the PD and Control groups produced significantly more runs – and by inference pauses – in the Slow condition as compared to the Habitual condition (Table 3). A similar trend held for the MS group, although run counts – and thus pause counts - were not statistically different for the MS group's Habitual and Slow conditions. The increased frequency of pauses in the Slow condition was further associated with at least some reduction in the proportion of pauses occurring at grammatically appropriate locations (Figure 3). Atypical pause locations can pose a challenge to perceptual processes required to recover a speaker's intended message (see review in Liss, 2007). The current findings therefore suggest the importance of incorporating pause placement training in treatment programs targeting voluntary rate reduction (for a similar suggestion concerning rate reduction using computerized pacing software see Hammen & Yorkston, 1996). Attention to pause placement would seem to be an important area of emphasis for the present speakers with MS and PD given that their Habitual speech was characterized by a reduced proportion of grammatically appropriate pauses as compared to the Control group.

Finally, the PD and MS groups but not the control group significantly lengthened average pause durations in the Slow condition (upper panel Figure 2). The increase in average pause duration was not sufficiently large to yield significant group differences in speech-pause ratios within the Slow condition. However, the tendency for speakers with MS and PD to pause more frequently in the Slow condition versus Habitual, the fact that disordered speaker groups significantly increased average pause durations for the Slow condition, and the finding of no significant group differences in speech rate for either the Habitual or Slow conditions suggests a trend for speakers with PD and MS to rely more on pause time to achieve a slower-than-habitual speech rate. Thus, in addition to training shorter phrases comprised of fewer syllables, rate reduction training programs for dysarthria might consider training longer and more frequent pauses – with attention to the grammatical appropriateness of pauses, as previously discussed.

### 4.2. Habitual Speech Rate Characteristics

Habitual speech rate, average articulation rate, average run duration, average number of syllables per run, and pause frequency - as inferred from speech run counts – did not differ for speakers with MS, speakers with PD and healthy controls. These results are consistent with other studies indicating that measures of global speech timing may be within normal limits for speakers with mild to moderate dysarthria secondary to PD or MS – at least for global speech timing measures obtained for a reading passage (see also Hartelius, Nord & Buder, 1995; Huber & Darling, 2011; Logeman et al., 1978; Tjaden, Sussman, Liu & Wilding, 2010). Whether this result holds for extemporaneous speech tasks remains to be determined. Global timing characteristics for a reading passage are known to differ in at least some respects from extemporaneous speech even for healthy talkers, and there is some evidence that these differences are more pronounced in dysarthria secondary to PD (Bunton, 2005; Huber & Darling, 2011; Schulz et al., 2004).

In contrast to the finding that global measures of speech timing for the Habitual condition did not differ among speaker groups, speech-pause ratios for the PD group were reduced compared to the Control group. The interpretation is that speakers with PD devoted a relatively greater proportion of habitual speech rate to pausing. On average, speech-pause ratios for the MS group also were reduced relative to the control average, although not to the same extent as for the PD group (Figure 4). Similar results have been reported in other studies of PD and MS (Nishio & Niimi, 2001; Hammen & Yorkston, 1996; Hartelius et al., 1995). These results suggest the importance of global timing studies including measures of speech-pause ratios as well as global timing measures such as speech rate or articulation rate, as these latter measures may not be sufficiently sensitive to differences in speech timing for individuals with mild to moderate dysarthria as compared to healthy controls.

### 4.3. Limitations and Summary

The present study has several limitations. An objective measure of speech severity in the form of a published single word or sentence intelligibility test was not obtained. Rather, three speech pathologists provided a consensus impression of dysarthria severity based on audio-recordings of clinical speech samples and a group of student listeners scaled speech severity for the Grandfather Passage. The current study is not unique in this regard (Huber & Darling, 2011; Schulz et al., 2004; Van Nuffelen et al., 2010), but speech severity estimates for the current speakers cannot be directly compared to those reported in other studies. Speaking rate characteristics for paragraph reading also have been shown to differ in some respects from spontaneous speech tasks, and there is some evidence that these types of task differences are magnified in dysarthria (Bunton, 2005; Huber & Darling, 2011; Schulz et al., 2004). Findings from the present study therefore may not directly translate to spontaneous speech. Studies investigating voluntary rate reduction for extemporaneous speech tasks would help to address this issue. Finally, speech rate adjustments elicited using a magnitude production paradigm may differ from those elicited within the context of an interactive, clinician-directed training program for voluntary rate reduction.

In summary, all speaker groups adjusted articulation time as well as pause time to reduce overall speech rate. Group differences in how voluntary rate reduction was accomplished were primarily one of quantity or degree. Articulation time adjustments included a tendency toward shorter speech runs comprised of fewer syllables as well as a reduction in average articulation rate. Pause time adjustments included an increase in pause frequency as well as a lengthening of average pause duration. To the extent that training programs focusing on voluntary rate reduction should emphasize existing skills or strategies, these variables might be considered for attention in dysarthria training programs focusing on rate reduction. Findings further suggest that a model of voluntary speech rate reduction based on neurologically normal speech shows promise as being applicable for mild to moderate dysarthria.

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## References

Ball L, Beukelman DR, Pattee GL. Timing of speech deterioration in people with amyotrophic lateral sclerosis. Journal of Medical Speech-Language Pathology. 2002; 10:231–235.

Bunton K. Patterns of lung volume use during an extemporaneous speech task in persons with Parkinson's disease. Journal of Communication Disorders. 2005; 38:331–348. [PubMed: 15963334]

Dagenais P, Southwood M, Lee T. Rate reduction methods for improving speech intelligibility of dysarthric speakers with Parkinson's disease. Journal of Medical Speech-Language Pathology. 1998; 6:143–157.

Duffy, JR. Motor Speech Disorders: Substrates, Differential Diagnosis, and Management. 2. St. Louis: Mosby; 2005.

Goberman AM, Elmer LW. Acoustic analysis of clear versus conversational speech in individuals with Parkinson disease. Journal of Communication Disorders. 2005; 38:215–230. [PubMed: 15748725]

Hammen V, Yorkston KM. Speech and pause characteristics following speech rate reduction in hypokinetic dysarthria. Journal of Communication Disorders. 1996; 29:429–445. [PubMed: 8956101]

Hartelius L, Nord L, Buder E. Acoustic analysis of dysarthria associated with multiple sclerosis. Clinical Linguistics and Phonetics. 1995; 9:95–120.

Henderson A, Goldman-Eisler F, Skarbek A. Sequential Temporal patterns in spontaneous speech. Language and Speech. 1966; 9:207–216.

Huber JE, Darling M. Effect of Parkinson's disease on the production of structured and unstructured speaking tasks: Respiratory physiologic and linguistic considerations. Journal of Speech Language and Hearing Research. 2011; 54:33–46.

Kleinow J, Smith A, Ramig LO. Speech motor stability in IPD: Effects of rate and loudness manipulations. Journal of Speech, Language, and Hearing Research. 2001; 44:1041–1051.

Liss, J. The role of speech perception in motor speech disorders. In: Weismer, G., editor. Motor speech disorders. San Diego: Plural; 2007. p. 187-220.

Logemann JA, Fisher HB, Boshes B, Blonsky ER. Frequency and Co-occurrence of Vocal Tract Dysfunctions in the Speech of a Large Sample of Parkinson Patients. Journal of Speech and Hearing Disorders. 1978; 43:47–57. [PubMed: 633872]

Lowit A, Brendel B, Dobinson C, Howell P. An investigation into the influences of age, pathology and cognition on speech production. Journal of Medical Speech Language Pathology. 2006; 14:253–262. [PubMed: 19330040]

Milenkovic, P. TF32. [Computer Program]. University of Wisconsin; Madison: 2002.

McHenry MA. The effect of pacing strategies on the variability of speech movement sequences in dysarthria. Journal of Speech, Language, and Hearing Research. 2003; 46:702–710.

McRae, Paul A.; Tjaden, Kris; Schoonings, Barbra. Acoustic and Perceptual Consequences of Articulatory Rate Change in Parkinson Disease. Journal of Speech Language and Hearing Research. 2002; 45:35–50.

Nishio M, Niimi S. Speaking rate and its components in dysarthric speakers. Clinical Linguistics & Phonetics. 2001; 15:309–317.

Schulz G, Greer M, Friedman W. The effects of pallidotomy surgery on sentence measures across three tasks in Parkinson's patients. Journal of Medical Speech-Language Pathology. 2004; 12:195–205.

Turner GS, Weismer G. Characteristics of speaking rate in the dysarthria associated with amyotrophic lateral sclerosis. Journal of Speech and Hearing Research. 1993; 36:1134–1144. [PubMed: 8114480]

Tjaden K, Sussman J, Liu G, Wilding G. Long-term average spectral (LTAS) measures of dysarthria and their relationship to perceived severity. Journal of Medical Speech-Language Pathology. 2010; 18:125–132.

Tjaden K, Wilding GE. Rate and loudness manipulations in dysarthria: acoustic and perceptual findings. Journal of Speech Language & Hearing Research. 2004; 47:766–783.

Tjaden K, Wilding GE. The impact of rate reduction and increased loudness on fundamental frequency characteristics in dysarthria. Folia Phoniatrica et Logopaedica. 2011; 63:178–186. [PubMed: 20938199]

Turner GS, Tjaden K, Weismer G. The influence of speaking rate on vowel space and speech intelligibility for individuals with amyotrophic lateral sclerosis. Journal of Speech & Hearing Research. 1995; 38:1001–1013. [PubMed: 8558870]

Van Nuffelen G, De Bodt M, Vanderwegen J, Van de Heyning P, Wuyts F. Effect of rate control on speech production and intelligibility in dysarthria. Folia Phoniatrica Logopaedica. 2010; 62:110–119.

Van Nuffelen G, De Bodt M, Wuyts F, Van de Heyning P. The effect of rate control on speech rate and intelligibility in dysarthria. Folia Phoniatrica Logopaedica. 2009; 61:69–75.

Yorkston KM, Hakel M, Beukelman DR, Fager S. Evidence for effectiveness of treatment of loudness, rate, or prosody in dysarthria: a systematic review. Journal of Medical Speech-Language Pathology. 2007; 15:xi–xxxvi.

Yunusova Y, Weismer G, Kent RD, Rusche NM. Breath-group intelligibility in dysarthria: characteristics and underlying correlates. Journal of Speech Language & Hearing Research. 2005; 48:1294–1310.

Research Highlights

- PD and MS groups effected a reduction in speech and articulation rate
- Nature of adjustments in articulation and pause time were similar across groups
- Trend for PD and MS groups to rely more strongly on pause time to reduce rate
- Descriptive model of rate reduction for normal speech shows promise for dysarthria

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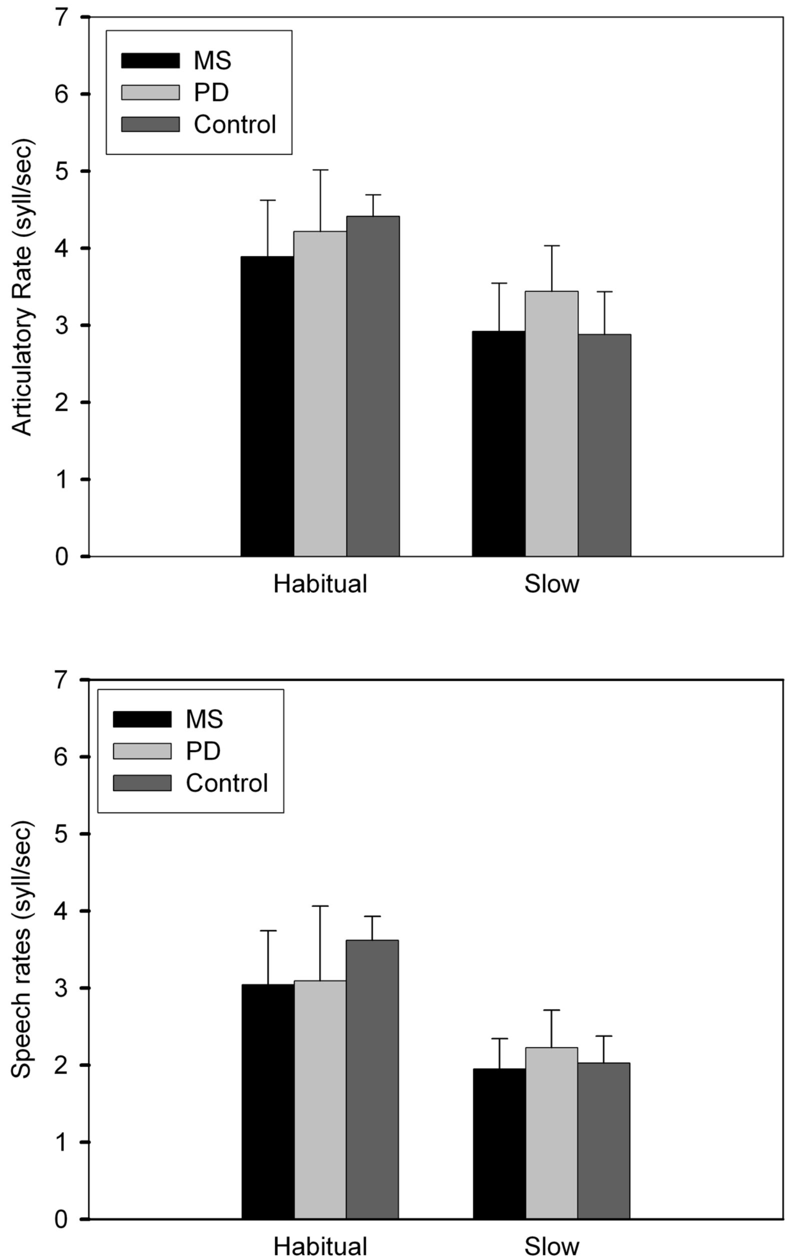


**Figure 1.**
Average articulatory rates and standard deviations are reported in the upper panel as a function of speaker group and condition. Data for speaking rate are reported in the lower panel.

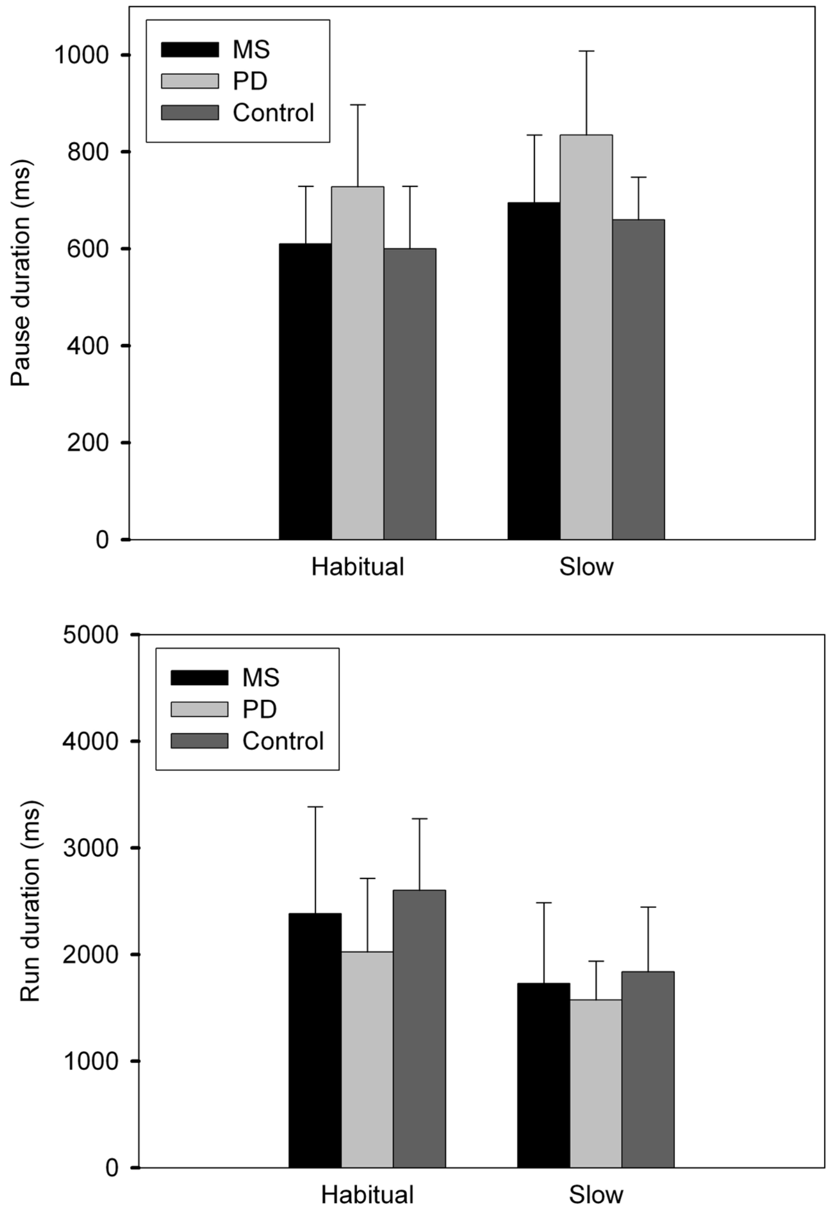


**Figure 2.**

Average pause durations and standard deviations are reported in the upper panel as a function of speaker group and condition. Average run durations and standard deviations are reported in the lower panel of this figure.

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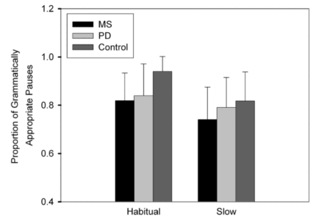


**Figure 3.**
The average proportion of grammatically appropriate pauses is reported as a function of speaker group and condition. Standard deviations also are shown.

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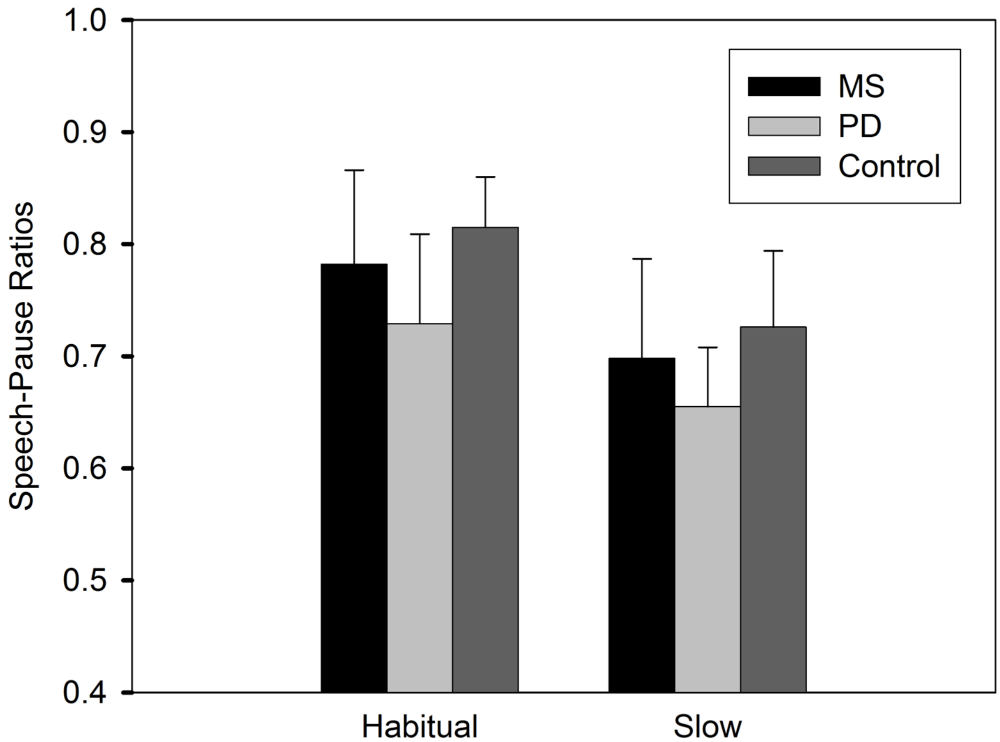


**Figure 4.**
Average speech/pause ratios are reported. Standard deviations also are shown. These ratios reflect the relative proportion of the reading passage devoted to articulation time. Ratios greater than .5 indicate that a relatively larger proportion of the reading passage was devoted to articulation time as compared to pause time.

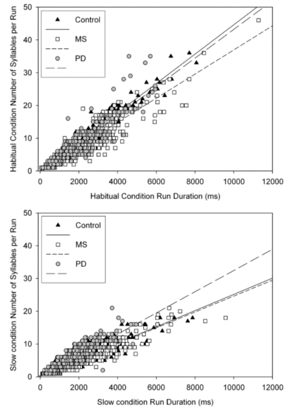


**Figure 5.**

The relationship between run duration (ms) and the number of syllables per run is reported. The upper panel reports data for the Habitual condition, and the lower panel reports data for the Slow condition. Linear regression functions have been fit to the data for each speaker group.

**Table 1**

Speaker characteristics for participants diagnosed with Multiple Sclerosis. Judgments of dysarthria severity and deviant perceptual characteristics were performed by three speech pathologists. Scaled estimates of intelligibility were provided by student listeners.

| Subject code | Age | Years Post Diagnosis | Dysarthria Diagnosis | Dysarthria Severity | Deviant Perceptual Characteristics | Scaled Intelligibility |
|---|---|---|---|---|---|---|
| MSF1 | 60 | 12 | Spastic | Moderate | Strain-strangled, slow rate, short phrases | 29 |
| MSF2 | 42 | 8 | Spastic-Ataxic | Mild | Low pitch, imprecise cons., excess and equal stress | 238 |
| MSF3 | 33 | 5 | Spastic | Moderate | Strain-strangled, slow rate, voice tremor | 57 |
| MSF4 | 50 | 9 | Ataxic | Mild/Moderate | Hyponasal, excess and equal stress, monopitch | 70 |
| MSF5 | 41 | 12 | Ataxic | Mild/Moderate | Hyponasal, irregular artic. breakdown, harsh | 100 |
| MSF6 | 56 | 7 | Spastic | Mild | Low pitch, harsh, slow rate | 183 |
| MSF7 | 59 | 15 | Ataxic | Moderate | Hyponasal, excess and equal stress, imprecise cons. | 65 |
| MSF8 | 25 | 5 | Spastic-Ataxic | Moderate | Excess and equal stress, slow rate, short phrases | 112 |
| MSF9 | 50 | 9 | Ataxic | Moderate | Slow rate, imprecise cons., irregular artic breakdown | 61 |
| MSF10 | 54 | 5 | Spastic | Mild | Slow rate, strain-strangled, pitch breaks | 241 |
| MSM2 | 45 | 4 | Ataxic | Moderate | Slow rate, monopitch, irregular artic breakdown | 91 |
| MSM3 | 58 | 8 | Spastic | Mild | Strain-strangled, harsh | 170 |
| MSM5 | 62 | 5 | Ataxic | Mild | Excess and equal stress, harsh, voice tremor | 168 |
| MSM6 | 47 | 2 | Ataxic | Mild | Hyponasal, imprecise cons, voice tremor | 97 |
| MSM7 | 48 | 21 | Ataxic | Moderate | Hyponasal, monopitch, monoloud | 74 |

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**Table 2**

Speaker characteristics for participants diagnosed with Parkinson Disease. Intelligibility refers to scaled intelligibility for the reading passage produced in the Habitual condition. See section in text entitled "Listening Task" for interpretation of the intelligibility estimates.

| Subject code | Age | Years Post Diagnosis | Dysarthria Diagnosis | Dysarthria Severity | Deviant Perceptual Characteristics | Scaled Intelligibility |
|---|---|---|---|---|---|---|
| PDF1 | 42 | 6 | Hypokinetic | Moderate | Monoloud, reduced loudness, variable rate | 146 |
| PDF2 | 62 | 3 | Hypokinetic | Mild | Imprecise cons., slow rate | N/A |
| PDF3 | 50 | 3 | Hypokinetic | Moderate/Severe | Hypernasal, imprecise cons., short rushes | 38 |
| PDF4 | 72 | 9 | Hypokinetic | Moderate | Reduced loudness, variable rate, short rushes | 115 |
| PDF5 | 81 | 3 | Hypokinetic | Severe | Repeated phonemes, low pitch, reduced loudness | 27 |
| PDF6 | 45 | 13 | Hypokinetic | Moderate/Severe | Fast rate, breathy voice, monoloud | 95 |
| PDM1 | 69 | 12 | Hypokinetic | Moderate | Monopitch, monoloud, reduced stress | 168 |
| PDM2 | 74 | 1 | Hypokinetic | Mild | Breathy, low pitch, slow rate | 100 |
| PDM3 | 72 | 4 | Hyperkinetic | Mild | Harsh, forced insp./expiration, low pitch | 178 |
| PDM4 | 64 | 17 | Hypokinetic | Moderate | Monopitch, monoloud, short rushes | 78 |
| PDM5 | 60 | 8 | Hypokinetic | Moderate | Breathy, short rushes, repeated phonemes | 80 |
| PDM6 | 64 | 8 | Hypo/Hyperkinetic | Mild/Moderate | Breathy, fast rate, voice stoppages | 81 |

**Table 3**

Mean number of runs, and by inference pauses, as well as number of syllables per run are reported for each group and condition. Standard deviations are reported in parentheses.

| | Run count | Run Count | Syllables per run | Syllables per run |
|---|---|---|---|---|
| | **Habitual** | **Slow** | **Habitual** | **Slow** |
| MS | 33 (16) | 62 (35) | 9.26 (4.31) | 4.75 (1.99) |
| PD | 35 (16) | 52 (22) | 8.80 (4.83) | 5.38 (1.54) |
| Control | 23 (8) | 53 (19) | 11.56 (3.12) | 5.10 (1.70) |

## Table 4

Mean run durations (milliseconds) as well as number of syllables per run are reported as a function of group and condition. Standard deviations are reported in parentheses.

| | Run Duration | Run Duration | Syllables per Run | Syllables per run |
|---|---|---|---|---|
| | **Habitual** | **Slow** | **Habitual** | **Slow** |
| MS | 2384 (1003) | 1730 (757) | 9.26 (4.31) | 4.75 (1.99) |
| PD | 2025 (689) | 1547 (366) | 8.80 (4.83) | 5.38 (1.54) |
| Control | 2604 (669) | 1839 (608) | 11.56 (3.12) | 5.10 (1.70) |