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Relative Speech Timing in Parkinson Disease

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The speech deficits that are commonly associated with Parkinson disease[1] (PD) are a form of hypokinetic dysarthria. Perceptual features of hypokinetic dysarthria include monopitch, monoloudness, and voice quality deficits, in addition to inappropriate silences, short rushes of speech, and variable speech rate (Darley, Aronson, & Brown, 1969). Studies of the rate and duration of Parkinsonian speech report varied results, as some researchers have found increased rate of speech (e.g., Forrest, Weismer, & Turner, 1989) and others have found rates similar to or slower than that of normal speakers (e.g., Weismer, Jeng, Laures, Kent, & Kent, 2001).

Forrest et al. (1989) and Weismer (1984) examined sentence reading in participants with PD and found that participants with PD produced shorter segment durations (i.e., faster rates) than did controls. Flint, Black, Campbell-Taylor, Gailey, and Levinton (1992) also found increased speech rates in individuals with PD. Alternatively, Ludlow, Connor, and Bassich (1987) noted a trend toward slower production of sentences in the speech of participants with PD. Several other speech studies reported that the speech rates of participants with PD were similar or equal to rates measured from control speakers (Canter, 1963; Connor, Ludlow, & Schulz, 1989; Metter & Hanson, 1986; Weismer et al., 2001).

In addition to studies of speech rate, a number of studies have examined the pause characteristics of Parkinsonian speech. There is general agreement that individuals with PD produce longer pauses than control participants, both in studies that objectively measured pauses (Metter & Hanson, 1986; Nishio & Niimi, 2001) and in studies that examined perception of pausing (Darley et al., 1969; Torp & Hammen, 2000). Overall, previous research found increased pausing in Parkinsonian speech, and examinations of rate in participants with PD have found faster, slower, or similar rates as compared to controls. In addition to these absolute measurements of speech timing, some researchers have examined PD and non-PD timing characteristics using *relative* speech timing measures.

In speech and nonspeech movement studies, relative timing typically has been measured by developing ratios

ABSTRACT: Relative speech timing was examined in individuals with Parkinson disease (PD) and in age-matched control speakers. Relative timing ratios were created from temporal intervals in one phrase containing no pause, one phrase containing an optional pause, and one phrase containing a mandatory pause. Results indicated that there were no relative timing differences between participants with PD and the controls. However, there were subtle differences in PD participant to control participant comparisons when examined in relation to the expected pause location. Overall, these data support previous studies, which found that speech relative timing is invariant on natural tasks despite changes in absolute timing. In addition, these data support the contention that speech relative timing is constrained by the physiology of the speech production system.

KEY WORDS: Parkinson, speech, acoustic, relative timing

[1]We have decided to omit the possessive ('s) from the eponym "Parkinson's disease." It has been recommended that the possessive form of eponyms be used only when the person for whom the disease is named was afflicted with that disease (Haines & Olry, 2003), and James Parkinson did not have Parkinson disease. Further, the current edition of the *American Medical Association Manual of Style* (Iverson et al., 1998) recommends that in the interest of clarity in scientific writing, "the possessive be omitted from eponymous terms" (p. 471).

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after segmenting an event into individual temporal segments. Prosek, Montgomery, and Walden (1988) separated individual temporal segments into an acoustic period (i.e., a temporal measure from within a sample) and an acoustic latency (i.e., a second temporal measure from within the same sample that may or may not overlap the period). Prosek et al. then divided each period by a corresponding latency to create ratios. In examining relative speech timing, most studies have used combinations of overlapping segments and nonoverlapping segments (e.g., Prosek et al., 1988; Robb & Pang-Ching, 1992; Weismer & Fennell, 1985). Specific segment locations have been chosen based on their acoustic distinctiveness (Robb & Pang-Ching, 1992), their location at CV or VC junctures (Weismer & Fennell, 1985), or their boundary types (i.e., shared or unshared boundaries) (Prosek et al., 1988).

Several studies have found the ratio of period to latency to remain constant under varying conditions and among various groups. Tuller, Kelso, and Harris (1982) examined conversational and fast repeated syllable productions and found consistent relative timing of speech muscle activations regardless of rate changes. Prosek et al. (1988) examined acoustic data from one sentence spoken by 15 speakers who stuttered and 15 normally fluent speakers. They found a rate difference between the fluent utterances of those who stuttered and normally fluent participants, but they found no significant difference in relative speech timing between the groups (Prosek et al., 1988). Another study examining relative timing of speech was performed by Robb and Pang-Ching (1992). These researchers examined speech timing in speakers with hearing impairments and normally hearing speakers and found that relative timing remained constant at different absolute durations of speech segments (i.e., rate differences) (Robb & Pang-Ching, 1992).

The speech of individuals with PD has also been examined using relative timing measures. McRae, Tjaden, and Schoonings (2002) found that the relative change in duration of segments was similar for individuals with PD and control participants across rate-change tasks, even though participants with PD tended to speak faster. Similar results were reported by Weismer and Fennell (1985), who examined rate-change tasks and found relative timing of speech to be constant across rates for control participants and those with neurological conditions, including PD. Ludlow et al. (1987) examined the timing of speech in participants with PD and Huntington disease as compared to control participants. They measured the word, phrase, and sentence durations in two sentences produced at regular and fast rates. Relative timing ratios of phrase to sentence time and word to phrase time were found to remain constant across both speaking rates for both disordered groups and the control group (Ludlow et al., 1987).

Max and Caruso (1997) recorded normal speakers producing the utterance “Buy Bobby a puppy” at three different speech rates. From these productions, they measured temporal intervals corresponding to a period and latency and used these to develop relative timing ratios. The researchers reported significant differences in relative timing for different speech rates, at both the syllable and the phrase level (Max & Caruso, 1997). Volkmann, Hefter, Lange, and Freund (1992) studied relative timing during a rate change task in participants with PD, Huntington disease, and Wilson disease. Based on an analysis of repeated sentence productions, they found overall constancy of relative timing; however, some participants with PD showed some variations in relative timing as well as “chaotic patterns” of speech (Volkmann et al., 1992).

Previous examinations of absolute speech timing (i.e., rate) have shown that individuals with PD show either faster or slower rates as compared to control participants. Examinations of rate-change tasks in individuals with PD reported no differences in relative timing compared to control participants, whereas one study reported some nonsignificant differences. Although relative timing of speech in individuals with PD has been examined based on rate-change tasks, a comprehensive description of relative timing has not been completed based on habitual rate tasks, or relative to pausing in the speech sample.

The purpose of this study was to examine the relative timing of Parkinsonian speech based on multiple phrases selected from a standard reading passage that was read at a self-determined habitual rate. Given the fact that pause differences exist between individuals with PD and controls (Goberman & Coelho, 2002), three phrases were selected based on their location relative to pauses occurring within the passage. It was hypothesized that there would be differences in relative timing between individuals with PD and control participants, as well as differences between different phrase-pause types in individuals with PD.

METHOD

Participants

Nine participants (3 females, 6 males) with idiopathic PD participated in this study after completing the informed consent process. The present study is one of a series of studies examining speech production in the same group of participants (Goberman & Blomgren, 2003; Goberman, Coelho, & Robb, 2002; Goberman, Coelho, & Robb, in press). No participants had any other neurological diagnoses besides idiopathic PD. Participants ranged from 57 to 83 years of age (M = 69 years) and were 3 to 19 years post PD diagnosis (M = 11.4 years). All participants were being treated with levodopa-carbidopa medication (i.e., Sinemet), and all participants passed a pure-tone hearing screening or wore hearing aids during recording sessions. Based on Section 3 of the Unified Parkinson’s Disease Rating Scale (UPDRS; Fahn, Elton, & members of the UPDRS Development Committee, 1987), participants’ motor severity ranged from 24 to 81 (M = 39.2) on a scale from 0 *(normal)* to 108 *(severely impaired)*. Finally, two experienced speech-language pathologists determined that all participants had hypokinetic dysarthria based on perceptual criteria determined by Darley et al. (1969). Dysarthria severity ranged from mild to moderate–severe, with 6 of 9 participants being rated as either mild–moderate or moderate.

Data were also collected from 8 control participants who were matched for age and gender as closely as possible with the PD participants (1 control participant was matched with 2 PD participants; *M* age = 69 years). Control participants had no history of speech or language disorders, and all passed a pure-tone hearing screening. All control participants were judged to have normal speech and language abilities for their age.

Data Collection

Participants with PD were recorded 30 min before taking their normal morning levodopa-carbidopa medication, and all participants had withdrawn from their medication at least 8 hr over the previous night. Recordings were scheduled to capture participants' speech while they were experiencing relatively low dopamine levels (i.e., OFF medication state). Control participant recordings took place at approximately the same time of day as the recordings for the participants with PD.

Each participant was given the opportunity to practice the reading before the first session in an attempt to minimize participant anxiety. In addition to other speech tasks not relevant to the current study, participants were asked to read the first paragraph of the "Rainbow Passage" (Fairbanks, 1960). Reading samples were collected on high-quality cassette tapes and transferred to Computerized Speech Lab (CSL 4400, Kay Elemetrics) for analysis. Speech samples were digitized and displayed as wide-band spectrograms for time interval measurement.

Data Analysis

Three phrases from the "Rainbow Passage" were analyzed, chosen for their linguistic pause characteristics. The first phrase, "beautiful colors. These take," was chosen as the mandatory pause phrase (MPP) because it crosses a sentence boundary. The second phrase, "path high above and its," was chosen to represent an optional pause phrase (OPP). The third phrase, "boiling pot of gold," was selected as a no pause phrase (NPP). Each phrase was broken down into eight temporal segments, each determined to be either a latency or a period. These segments were used to create four relative timing ratios by dividing each latency by its corresponding period. Overall, there were 24 segments taken from 3 phrases, and these segments were used to calculate 12 relative timing ratios. Segments and ratios for the NPP matched those used by Robb and Pang-Ching (1992) for this same phrase to allow comparison with these previous data. Segments for the OPP and MPP were chosen so that all segments were bounded by acoustic–phonetic markers (Robb & Pang-Ching, 1992) that could be identified reliably on the spectrograms of the samples (e.g., at a VC interface). In addition, segments for the OPP and MPP were chosen to ensure an equal distribution of overlapping and nonoverlapping segments (Prosek et al., 1988; Weismer & Fennell, 1985). For example, the MPP phrase contains two nonoverlapping segments (Ratios A and C) and two overlapping segments (Ratios B and D). See Figure 1 for further description of phrases, segments, and ratios.

The values for temporal segments (i.e., latencies and periods) were determined by measuring the time intervals between acoustic–phonetic markers for each phrase. Phonetic markers most often were stop bursts or the initiation or termination of voicing for a vowel; fricative and nasal markers were also used. Each phrase included up to six acoustic-phonetic markers used to determine segments (see Figure 1).

Reliability

To determine intrajudge reliability, data from 2 participants with PD and 1 control participant were reanalyzed (i.e., 18% of total data reanalyzed). Pearson-product moment correlation (PPMC) analysis revealed significant correlations for all intrajudge comparisons ($r = 0.99–1.00$; $p < 0.05$). Interjudge reliability was determined by analysis of the same data by another researcher. This PPMC analysis revealed significant correlations for all interjudge comparisons ($r = 0.98–1.00$; $p < 0.05$).

Data Analysis

Statistical significance testing was completed using the Mann-Whitney *U* test (alpha level = 0.05). Because of the small sample size ($N = 9$), effect size (η^2) analysis was also completed to measure degree of association between the independent and dependent variables (Meline & Schmitt, 1997; Young, 1993).

RESULTS

Table 1 lists means, standard deviations, and ranges for the PD and control participants' ratios. Data were analyzed for all 9 control–PD participant pairs, with the exception of OPP for PD7. The data for this participant could not be analyzed because of reading errors in that phrase.

In comparing ratios from the PD participants' data to age-matched control data (see Table 2), Mann-Whitney *U* tests revealed no significant differences for the MPP ($p > 0.05$), with effect sizes for this comparison ranging from 0.021 to 0.069 (M $\eta^2 = 0.044$). For the OPP, there was also no statistically significant difference between the control participants and the participants with PD ($p > 0.05$). The mean effect size for the OPP comparison was 0.023, with values ranging from 0.006 to 0.035. The NPP data were similar to the previous phrase types, as there was no statistically significant difference between PD and control participants ($p > 0.05$), along with low effect sizes (M $\eta^2 = 0.099$; range = 0.000–0.142). Although effect size values were low overall, comparing mean effect sizes among the phrase types revealed that the mean effect size for the NPP was more than twice as high as the mean MPP effect size, and more than four times higher than the mean OPP effect size.

Figure 1. Segments and ratios for the mandatory pause phrase (MPP) "beautiful colors. These take," optional pause phrase (OPP) "path high above, and its," and no pause phrase (NPP) "boiling pot of gold." Each ratio was determined by the latency (upper segment, dotted lines) divided by the period (lower segment, solid lines). The hatched vertical lines represent the typical pause location for the MPP and OPP.

DISCUSSION

This study examined relative speech timing in individuals with PD before taking their morning levodopa-based medication, and compared these results to data collected from age-matched control participants. Relative timing ratios were created by measuring temporal intervals in one MPP, one OPP, and one NPP. The results showed no differences between the relative speech timing ratios of the individuals with PD and their age-matched controls. However, there were subtle differences in the comparisons when examined in relation to the expected pause location.

With the exception of Max and Caruso (1997), who found relative timing differences related to rate change, recall that previous researchers generally found no statistically significant differences in relative timing of speech when comparisons were made between different speaking rates in unimpaired speakers (e.g., Tuller et al., 1982) or between unimpaired speakers and individuals with hearing loss (Robb & Pang-Ching, 1992), fluency disorders (Prosek et al., 1988), or dysarthria (e.g., Weismer & Fennell, 1985). In interpreting their relative timing results, Weismer and Fennell proposed a theory that the speech mechanism "imposes rigid constraints on the temporal characteristics of an articulatory sequence" (p. 55) and that temporal patterns of articulatory movements are "highly constrained by the requirements of fluency" (p. 54). Other research has also supported this theory. For example, even though there is evidence that the timing and articulatory characteristics of fluent speech of individuals who stutter differ significantly from those characteristics of fluent speech of nonstutterers (e.g., Robb, Blomgren, & Chen, 1998; Zimmermann, 1980), Prosek et al. found no difference in relative speech timing, supporting the statement that relative timing is somehow constrained by the biology of the articulatory system. Similarly, although absolute rates among the groups differed, no differences in relative timing were found between participants with no hearing impairments and those with profound hearing impairments (Robb & Pang-Ching,

Table 1. Means and standard deviations for control and Parkinson disease participant relative timing ratios. Results are organized by phrase type: mandatory pause phrase (MPP), optional pause phrase (OPP), and no pause phrase (NPP).

	Control group			*Parkinson disease group*		
	Mean	SD	*Range*	*Mean*	SD	*Range*
MPP						
Ratio A	0.104	0.034	0.066–0.175	0.086	0.048	0.036–0.182
Ratio B	0.280	0.065	0.155–0.356	0.249	0.093	0.105–0.453
Ratio C	0.130	0.074	0.076–0.313	0.112	0.050	0.037–0.195
Ratio D	0.780	0.033	0.747–0.844	0.811	0.079	0.641–0.894
OPP						
Ratio A	0.971	0.308	0.588–1.396	0.861	0.355	0.579–1.516
Ratio B	3.279	0.627	2.375–4.432	3.374	0.730	2.352–3.986
Ratio C	15.213	9.339	8.877–38.634	18.200	11.950	7.299–38.264
Ratio D	10.243	6.459	4.548–25.686	13.008	8.989	5.852–27.685
NPP						
Ratio A	0.593	0.035	0.545–0.633	0.565	0.041	0.506–0.641
Ratio B	0.494	0.060	0.443–0.597	0.496	0.130	0.284–0.734
Ratio C	1.472	0.070	1.397–1.592	1.575	0.190	1.307–1.981
Ratio D	1.147	0.158	0.944–1.420	1.244	0.109	1.102–1.450

1992), or between nonneurologically impaired participants and participants with PD (Weismer & Fennell, 1985) or Huntington disease (Ludlow et al., 1987). Overall, past research has concluded that temporal characteristics of the speech production system are biologically constrained, as evidenced by findings of varying absolute timing (i.e., rate) coupled with statistically invariant relative timing.

A previous examination of the current group of participants found that the PD participants' articulation rates were no different than the rates of control participants (Goberman et al., in press). However, there were significant percent pause time differences between control participants and those with PD, as the individuals with PD were found to have higher percent pause times than controls. This previous finding, along with the fact that at least one of the three phrases analyzed contained a pause, led to the hypothesis that there would be a difference in relative speech timing between the PD and control speakers. Nevertheless, in the current study, no statistically significant differences were found between relative speech timing of the PD participants and age-matched controls. Because there are absolute timing (i.e., percent pause time) differences between these individuals with PD and controls, the finding of no relative speech timing differences supports the theory that relative timing of speech is constrained by the physiology of the speech production system.

Table 2. Mann-Whitney-*U* test results (*p* level; all nonsignificant) and effect size (η^2) results.

	p *level*	η^2
Mandatory pause phrase		
Ratio A	.269	.049
Ratio B	.233	.039
Ratio C	.627	.021
Ratio D	.102	.069
Optional pause phrase		
Ratio A	.211	.030
Ratio B	.630	.006
Ratio C	.596	.022
Ratio D	.441	.035
No pause phrase		
Ratio A	.085	.142
Ratio B	.825	.000
Ratio C	.085	.126
Ratio D	.122	.128

This experiment was set up not only to examine relative timing between control participants and those with PD, but also to allow an analysis of relative speech timing based on the phrase pause location (i.e., NPP, MPP, OPP). Although the current results found no statistically significant differences for any phrase pause location, further analysis was completed on the effect size values to examine the relative strength of each comparison (Meline & Schmitt, 1997). Hammen and Yorkston (1996) found that individuals with PD produced a similar-to-normal amount of pausing in syntactically appropriate locations and an increased proportion of pauses in syntactically inappropriate locations. Given this finding, it was expected that relative timing differences would have been greatest in the NPP and smallest in the MPP. Although these effect sizes are too small to allow further interpretation, the highest effect sizes were indeed found for the NPP, followed by MPP and OPP.

Nonspeech Relative Timing

Findings of nonspeech relative timing research can be used in interpreting the results of the current study as well as interpreting previous relative speech timing studies. Terzuolo and Viviani (1979) examined the timing of keypresses while typing at different overall speeds and found relative timing to be stable across rates. Viviani and Laissard (1991) examined 2 professional typists and also found relative timing to be constant across different absolute rates. In their interpretation of these results, they stated that one reason for consistent relative timing may have been biomechanical and physiological constraints affecting typing gestures. In addition to typing and speech, invariant relative timing has been found in handwriting (Viviani & Terzuolo, 1980) and arm movement (e.g., Carter & Shapiro, 1984).

Invariant relative timing has been found in multiple studies across multiple movement modalities (for further review, see Gentner, 1987; Schmidt, Heuer, Ghodsian, & Young, 1998); however, others have failed to find invariant relative timing (see Gentner, 1987). Therefore, there is still controversy over whether relative timing of human movement is truly invariant. Gentner proposed that the statistical analysis techniques used in previous studies have led to inappropriate conclusions of relative timing invariance. Heuer (1988) countered this argument with a proposal that it is still possible to have central relative timing invariance, although as a result of motor delays, peripheral measurements may indicate an apparent lack of invariance.

In discussing the effect of invariant relative timing on motor programming theory, Heuer (1991) stated that relative timing is invariant only when spatial constraints are constant and when the motor pattern is natural; further, relative timing of movement can break down when spatial constraints or naturalness are sacrificed. This naturalness effect may explain why only one examination of speech production found speech relative timing to be variable. Max and Caruso (1997) found variable relative timing as speaking rate was altered (slow, normal, and fast rates). Other studies of speech relative timing have generally either manipulated rates from normal to fast (e.g., Weismer & Fennell, 1985) or used natural variations in rate associated with disorders (e.g., Robb & Pang-Ching, 1992). It is possible that unnaturalness in the production of the "extremely slow" (Max & Caruso, 1997, p. 1108) rate of speech caused the overall significant differences in their study.

Overall, some nonspeech movement studies have found invariance of relative timing and used this as evidence for the existence of generalized motor programs affecting movement (e.g., Schmidt & Lee, 1999); others have failed to find invariance of relative timing (see Gentner, 1987, for review). A number of factors have been identified as prerequisites for invariant relative timing, including physiological constraints, spatial constraints, and naturalness. Therefore, it is not surprising that the current study found invariant relative speech timing in individuals with PD versus controls. All speech samples were natural reading, and speech production is constrained by the physiology of the articulatory system, as well as the spatial confines of the vocal tract.

FUTURE DIRECTIONS

One issue that should be considered in interpreting the present results is the selection of phrases to include in the current analysis. Three phrases were chosen from a standardized reading passage, such that there was one sentence that contained a mandatory pause, one that contained an optional pause, and one that contained no pauses. It is not believed that the selection of sentences obscured results; however, it is possible that results may have been stronger given the inclusion of additional phrases. Further, although three phrases were analyzed in the current study, previous relative speech timing studies have analyzed only one phrase (e.g., Max & Caruso, 1997; Robb & Pang-Ching, 1992) or two phrases (Weismer & Fennell, 1985).

A second possible issue is the selection of specific segments for the creation of acoustic ratios. The segments and ratios for the NPP, "boiling pot of gold," were a replication of the ratios used by Robb and Pang-Ching (1992), which were originally chosen for their acoustic distinctiveness. The other two phrases analyzed in the current study have not been examined for relative timing characteristics in the past; therefore, the segments and ratios created for the present study were unique. The choice of segments for these two phrases was based on ensuring reliable and repeatable data analysis, and this was supported by the high intrajudge and interjudge reliability found based on reanalyses of the current results. The choice of segments was also driven by an attempt to ensure an equal distribution of overlapping and nonoverlapping segments, as has been used in previous studies (e.g., Prosek et al., 1988; Weismer & Fennell, 1985). Although all reasonable attempts have been made to replicate previous designs within a new environment (i.e., in two new phrases), the design of this and similar studies should be considered in comparing results and planning future studies.

CONCLUSION

Results of the present study indicated that there were no relative timing differences between the individuals with PD and the controls. Because of the fact that there were absolute timing differences (i.e., percent pause time differences) between the participants with PD and their age-matched control participants even though no relative timing differences were found, these results provide further support for the theory that temporal characteristics of the speech production system are biologically constrained.

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