

Intra-participant variability in Parkinson's disease: An electropalatographic examination of articulation

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Abstract

The articulation of individuals with dysarthria has traditionally been described as consistent. However, conflicting findings have resulted from research examining intra-participant variation in the articulation of individuals with Parkinson's disease (PD) and hypokinetic dysarthria. The current study used electropalatography (EPG) to examine the degree of intra-participant variation in both tongue-palate contact patterns and duration of contact in a group of speakers with PD and hypokinetic dysarthria including consonant imprecision ($n = 8$). The study also aimed to determine if ageing contributed to any articulatory instability observed. Therefore, two control groups were employed consisting of aged adult ($n = 7$) and young adult ($n = 8$) speakers respectively. Participants were asked to read aloud the phrase "I saw a CVC today" where $C = /t/, /s/, \text{ and } /l/$ and $V = /a/$. Intra-participant variation in tongue-palate contact was measured using the absolute and relative variability indexes. Coefficients of variation of duration of tongue contact were employed to examine intra-participant variation in consonant duration. In contrast to the study hypotheses, similar levels of intra-participant variation were observed across the three groups. However, a trend towards increased intra-participant variation in consonant duration was noted in the group with PD. The results of the study suggest that, at least spatially, the articulatory errors of individuals with PD are consistent across repetitions. Research including increased participant numbers and individuals exhibiting greater severity of dysarthria is required to provide further understanding of intra-participant variation in consonant duration in PD.

Keywords: *Variability, hypokinetic dysarthria, Parkinson's disease, articulation, electropalatography.*

Introduction

Traditionally, the articulatory errors of individuals with dysarthria have been considered consistent in error location and type. Indeed, Duffy (2005) stated that "in dysarthria, deviant speech characteristics are generally consistent across utterances and are relatively uninfluenced by the degree of automaticity of the utterance, stimulus modality (e.g., spontaneous, reading, imitation), or linguistic variables" (p. 420). One form of dysarthria in which articulatory errors are common is hypokinetic dysarthria associated with Parkinson's disease (PD) (Logemann, Fisher, Boshes, & Blonsky, 1978).

Interestingly, it is generally accepted that across-trial variability is increased in movement disorders, such as PD, in which a motor programming deficit is assumed (Ziegler, Hartman, & Hoole, 1993). Parkinson's disease results from degeneration and loss of pigmented neurones within the pars compacta of the substantia nigra and in the locus ceruleus (Fahn, 1995); subsequently, interrupting the basal

ganglia control circuit. As the basal ganglia plays a role in motor programming (Van der Merwe, 1997), it is not unreasonable to suggest that across-trial variation in the spatial and temporal aspects of articulation will occur in individuals with PD and hypokinetic dysarthria. However, conflicting findings have been observed from research to date.

Zwirner and Barnes (1992) used acoustic analysis of sustained /a/ phonation to measure the upper airway and phonatory stability of 18 participants with PD compared to a control group. The results of the investigation found that the participant group with PD displayed a significantly higher root mean squared error of the first formant, indicating that jaw control may show signs of instability in individuals with PD. Furthermore, Wood, Hughes, Hayes, and Wolfe (1992) employed strain gauge instrumentation in the investigation of labial force in a group of 10 individuals with PD and reported that the participants with PD exhibited "appreciably larger within-subject trial-to-trial variability" (p. 255) when compared to control participants and groups of

individuals with other neurological disorders (CVA and multiple sclerosis).

In contrast to these findings, a report by Connor, Abbs, Cole, and Gracco (1989) observed reduced intra-participant variation in upper lip, lower lip, and jaw movement of a group of nine speakers with PD when data was quantified using coefficients of variation (CV). Connor et al. (1989) stated that “although group CV differences are small and do not allow definitive conclusions, movement limitations within PD subjects may restrict variability in the execution of orofacial movements for speech” (p. 1002). It can, therefore, be seen that conflicting findings have been reported for across-trial articulatory variability in speakers with PD. Indeed, research is currently lacking a clear picture of the characteristics of intra-participation articulatory variability in PD. In this line of research, concurrent observations of the across-trial variation in both the spatial and temporal aspects of articulation would be of use.

Electropalatography (EPG) presents a means of quantifying intra-participant variation in the spatial and temporal aspects of speech articulation. The technique has been used successfully in previous studies to examine variation in both patterns of tongue-palate contact (Farnetani & Provaglio, 1991; McAuliffe, Ward, & Murdoch, 2001) and the duration of contact with the hard palate in normal speakers (McAuliffe, Ward, & Murdoch, 2003). Presumably, if individuals with PD do exhibit increased across-trial variation in speech articulation, EPG will objectively reflect such variation. As a result, the current investigation primarily aimed to use EPG to examine the degree of intra-participant variation in both tongue-palate contact patterns and duration of tongue contact with the hard palate in individuals with PD and hypokinetic dysarthria including consonant imprecision. The investigation also had a secondary aim; to examine the influence of ageing upon variability of speech production. There is common consensus that instability in movements of the articulators is associated with ageing (Benjamin, 1997; Liss, Weismer, & Rosenbek, 1990); therefore, it is further hypothesized that while speakers with PD will demonstrate greater intra-participant variability than both the aged and young control speakers, the aged control speakers will exhibit greater intra-participant variation than young control speakers.

Methods

Participants

Three groups of speakers participated in the study. The first group consisted of eight individuals (seven males and one female) diagnosed with PD by a neurologist. The mean age of the group was 67 years (SD = 7 years) with an age range of 57 to 83 years. Specific biographical, medical and speech details of group with PD are located in Table I. Participants

were excluded from the group if they had any history of neurological disease or disorder with the exception of PD, a history of speech disorder with the exception of that associated with PD, surgery that involved the lips or tongue, drug and/or alcohol abuse, or dementia. All individuals in the group with PD exhibited hypokinetic dysarthria and varying degrees of consonant imprecision.

Two speech-language pathologists experienced in dysarthria research conducted perceptual analysis of the degree of overall intelligibility and consonant precision of the individuals with PD. Both judges listened independently to the randomized speech samples of the participants and rated intelligibility and consonant precision on the rating scale of FitzGerald, Murdoch, and Chenery (1987). On occasion where discrepancies in the ratings between the two judges were evident, a further rating session was conducted. During this rating session, both judges conferred to produce a single consensus rating for each dimension. This consensus rating is presented in Table I. Detailed analysis of the articulatory errors of the group with PD revealed that all errors were distortions of the target consonant. These errors were most commonly observed in the articulation of /s/ and /t/. For further details of this articulatory analysis the reader is directed to McAuliffe, Ward and Murdoch (2006a).

The remaining two groups were healthy non-impaired individuals used for comparative purposes. The two groups consisted of an aged adult control group (AC) and a young adult control group (YC). The ages of the AC participants were matched as closely as possible to those in the PD group. Each participant in the two control groups presented with perceptually normal speech as judged by a speech-language pathologist. The AC group consisted of seven males with a mean age of 67 years (SD = 8 years) and an age range of 50 to 79 years. The YC group comprised one male and seven females (mean age = 25 years, SD = 3 years) ranging in age from 23 to 31 years.

Experimental task

Three words embedded in the phrase “I saw a CVC today” (e.g., I saw a *tar*p today) were repeated ten times, in a random order, by each speaker. This resulted in a total of thirty phrases per speaker. The word-initial consonants investigated included the lateral approximant /l/ (*lar*k), alveolar fricative /s/ (*sar*ge) and the alveolar stop /t/ (*tar*p) in the /a/ vowel environment. All experimental stimuli were real words in Australian English and as Australian English is non-rhotic, none of the vowels were retroflexed.¹

Data collection

The Reading EPG system (both EPG3 and Windows EPG) was used to record the tongue-palate contacts

Table I. Biographical, medical, and speech details of the Parkinson's disease (n = 8).

Participant	Gender	Age	Years post-onset	Medication	Hoehn & Yahr	Overall Intelligibility	Consonant Imprecision
1	M	67	8	Madopar, Sinemet	3	1	2
2	M	62	6	Sinemet	3	3	3
3	M	74	4	Sinemet, Comtan	2	2	3
4	F	83	16	Sinemet	2	3	3
5	M	63	3	Sinemet	3	2	2
6	M	61	8	Madopar, Comtan	3	1	2
7	M	57	4	Madopar	3	2	3
8	M	71	5	Madopar	3	1	2

Note: Hoehn & Yahr = participants rating on the Parkinson's disease clinical disability scale (Hoehn & Yahr, 1967). Ratings on the scale range from 1 = mild symptoms through to 5 = requiring high level care. A rating of 2 = bilateral or midline involvement, without impairment of balance and 3 = mild to moderate impairment with some functional restrictions. Overall intelligibility and consonant imprecision were rated on a four-point scale where 1 = within normal limits, 2 = just noticeable impairment, 3 = moderate impairment, and 4 = severe impairment (FitzGerald, Murdoch, & Chenery, 1987). The ratings for overall intelligibility and consonant imprecision displayed are based on the consensus rating of two perceptual judges experienced in the rating of dysarthric speech.

and corresponding acoustic signal of each individual's speech output (Hardcastle, Gibbon, & Jones, 1991). For full details of the Reading EPG system see Hardcastle et al. (1991). Prior to assessment, all participants were fitted with an individually moulded thin acrylic palate (approximately one millimetre in thickness), embedded with 62 proportionally spaced touch-sensitive electrodes. Participants with PD were assessed, where possible, in the morning during an "on" medication phase to minimize the effects of medication cycle and fatigue upon speech production. The majority of control participants produced typical speech articulation as judged by a speech pathologist following 45 minutes of desensitization. However, three participants in the YC group continued to produce a slight perceptual distortion of /s/ on some repetitions after extended desensitization. These data remained in the final data set. For participants with PD, testing commenced when their speech was judged by the conducting speech pathologist to have returned to baseline. In most instances, this occurred within 45 minutes of insertion of the palate. Tongue-palate contact patterns were sampled in 10 millisecond intervals across the period of articulation of the target consonant. Acoustic data (used as a reference point only), simultaneously collected with the EPG data, was digitized and sampled at 10 kHz. All participants were assessed in a free field room to eliminate interference by external noise to the acoustic trace.

Data analysis

Initial data analysis. Data generated from the EPG assessment were analysed for intra-participant variability of tongue-palate contact patterns and duration of contact. However, initial analysis of the data set was required prior to undertaking the variability analysis. The results of this initial data analysis for tongue-palate contact patterns and duration of contact for the three groups have been published previously (McAuliffe et al., 2006a; McAuliffe,

Ward, & Murdoch, 2006b). However, a description of the initial data analysis methods follows.

Data were analysed using the EPGLAB program (Scott & Goozee, 2004), an in-house software program. The program was used to extract diagrammatic representations of tongue-palate contact across the articulation of the target consonant in 10ms intervals. Across these intervals, the EPG display identified the diagrammatic representation with the greatest amount of tongue-palate contact. This display was judged to be the most representative of tongue-palate contact for the target consonant for each individual. These diagrammatic representations of tongue-palate contact were combined for the ten repetitions of each target consonant spoken by each participant in the project to produce an individual representative frame (IRF) (McAuliffe et al., 2001) (see Figure 1).

The duration of tongue contact with the hard palate was calculated using EPGLAB totals displays. An identical procedure was undertaken for all consonants. The onset of contact was defined as the frame immediately before the number of contacted electrodes in the anterior half of the palate began to increase. End of contact was defined as the frame that immediately followed a steady decline in the number of contacted electrodes and the beginning of stable constriction for the following vowel.

Variability analysis

Intra-participant variability in tongue-palate contact. Intra-participant variability in tongue-palate contact patterns was examined using the absolute and relative variability indexes (Farnetani & Provaglio, 1991). These indexes employ the IRF to examine variation in tongue-palate contact with the hard palate across repeated trials of a consonant (Farnetani & Provaglio, 1991). The absolute variability index reflects the intra-participant variability in tongue-palate contact patterns when all electrodes on the palate (i.e., 62

	100	100	100	100	100	100	
100	100	100	80	100	100	100	100
100	100	70	20	30	60	90	100
100	30	0	0	0	0	10	100
100	10	0	0	0	0	0	100
100	0	0	0	0	0	0	100
100	0	0	0	0	0	0	100
100	0	0	0	0	0	0	100
100	0	0	0	0	0	0	100

Figure 1. An individual representative frame (IRF) across 10 repetitions of /t/ in a normal speaker. Each square contains a percentage value describing the number of times a specific electrode was contacted over the 10 repetitions of the target consonant.

electrodes) are considered. In contrast, the relative variability index considers the numbers of electrodes activated on the palate in its calculation. In the present study, the absolute and relative variability indexes were calculated using the participants' IRFs. Appendix 1 contains a worked example of these calculations over 10 repetitions of /t/.

Intra-participant variability in duration of contact. Coefficients of variation (CV) were used to examine intra-participant variation in duration of tongue-palate contact. The CV was considered appropriate as it allowed for comparison between different parameters (e.g., consonant) and between normal and disordered populations who may exhibit dissimilar mean values (Higgins, Netsell, & Schulte, 1994). The CV was calculated by dividing individual participant's standard deviation of consonant duration for specific consonants by their mean. This method of variability analysis has previously been employed in published EPG research (McAuliffe et al., 2003).

Results

Intra-participant variation in tongue-palate contact patterns

The results of the absolute and relative variability indexes are presented in Figures 2 and 3 respectively. A Kruskal-Wallis one-way analysis of variance procedure revealed no significant differences ($p > .05$) across the three groups on the absolute variability index for the articulation of /t/ ($H = .399$, $p = .819$), /s/ ($H = .972$, $p = .615$), and /l/ ($H = .249$, $p = .883$). Similarly, when the degree of tongue-palate contact was considered using the relative variability index, no significant differences were found across the three groups for the articulation of /t/ ($H = .705$, $p = .703$), /s/ ($H = .418$, $p = .811$), and /l/ ($H = .159$, $p = .924$). Individual participant results are presented in Appendix 2.

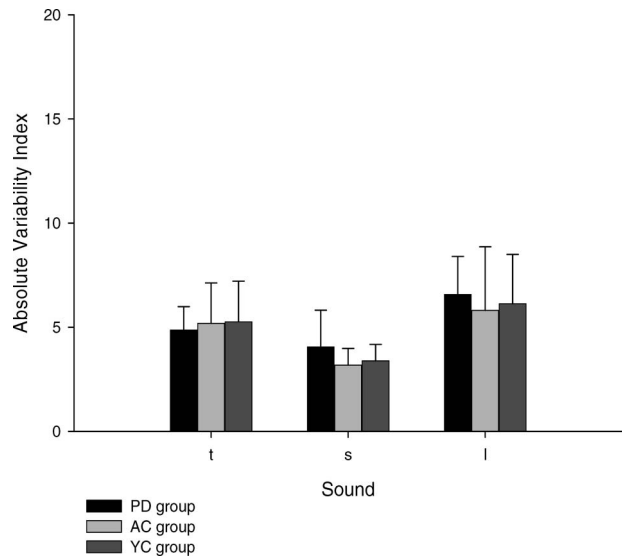


Figure 2. Absolute variability index over 10 repetitions of /t/, /s/, and /l/ across the three participant groups.

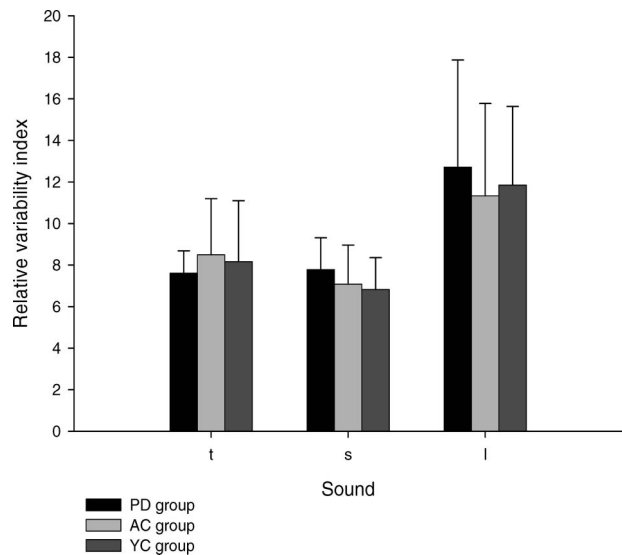


Figure 3. Relative variability index over 10 repetitions of /t/, /s/, and /l/ across the three participant groups.

Intra-participant variation in duration of tongue-palate contact

Figure 4 contains the group means and standard deviations for CV of duration of tongue contact with the hard palate across the three sounds. A clear trend towards increased intra-participant variation in the group with PD was observed across the sounds. However, statistical analysis did not substantiate this trend with Kruskal-Wallis one-way analyses of variance finding no significant differences across the three groups for /s/ ($H = 2.702$, $p = .259$), /t/ ($H = 4.604$, $p = .100$), or /l/ ($H = 1.592$, $p = .451$). For individual participant results, see Appendix 1.

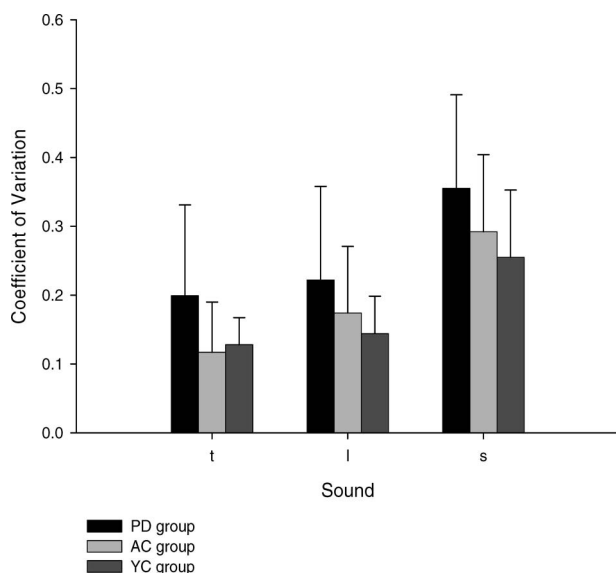


Figure 4. Coefficient of variation score for total duration of tongue contact with the hard palate across the three groups.

Discussion

The present study investigated the degree of intra-participant variation present in tongue-palate contact patterns and duration of tongue contact with the hard palate in three participant groups: speakers with PD and consonant imprecision, aged controls, and young controls. It was hypothesized that the group with PD would exhibit increased across-trial variation in both tongue-palate contact patterns and segment durations compared to the control groups. This hypothesis was based upon previous findings of increased intra-participant variation in jaw (Zwirner & Barnes, 1992) and lip movement (Wood et al., 1992) in speakers with PD and the expectation that impaired motor programming, associated with basal ganglia dysfunction (Van der Merwe, 1997), would result in increased across-trial variation. A secondary expectation of the study was that articulatory instability associated with increased age (Benjamin, 1997; Liss et al., 1990) would result in a continuum of intra-participant variation, with the aged control group exhibiting greater variation than the young control group.

In contrast to the hypotheses of this study, no significant differences were reported for intra-participant variation in either tongue-palate contact patterns or duration of tongue contact with the hard palate across the three groups. While the group with PD demonstrated mild to moderate consonant imprecision, their pattern and duration of tongue contact did not vary any more than those of the control groups on repeated trials of the target consonants. Furthermore, no age-related differences in articulatory variability were observed. While not examined directly, the pattern of results did indicate differing levels of intra-participant variability across consonants. Consistent with previous studies (Farnetani & Provaglio, 1991; McAuliffe et al.,

2001), increased intra-participant variation in tongue-palate contact patterns were observed for /l/ across the three groups. It is thought that this finding relates to the small amount of lateral stabilization occurring during /l/ production (McAuliffe et al., 2001). In addition, a consistent pattern of increased temporal variability was noted during the production of /s/ for all speaker groups. This pattern has been observed previously (McAuliffe et al., 2003) and likely relates to the complexity of the lingual gesture required for /s/ production.

Due to methodological differences, the findings of the current study cannot be directly compared with previous investigations. However, the observation of similar levels of intra-participant variation in the group with PD compared to the control groups contrasts with previous reports of both increased (Wood et al., 1992; Zwirner & Barnes, 1992) and decreased (Connor et al., 1989) intra-participant articulatory variation in PD. It is likely that the current findings reflect the mild to moderate nature of the articulatory impairments of the group with PD. That is, if the group exhibited higher levels of articulatory imprecision, greater instability in articulation may have resulted (Ziegler et al., 1993). Future studies would benefit from the inclusion of increased participant numbers and individuals with greater severity of articulatory impairment to determine if this is indeed the case. While it could be argued that reduced force of lingual contact with the hard palate may have contributed to the lack of variation observed in the group with PD, such an explanation appears unlikely on the basis of previous research (McAuliffe, Ward, & Murdoch, 2005) which reported similar levels of tongue strength in the PD and AC groups investigated. The repetitive nature of the experimental task and limited number of consonant investigated may also have been a factor in the similar levels of variation observed. Previous studies have reported variable results across speaking tasks (Kempner & Van Lancker, 2002), therefore, the inclusion of more complex articulatory experimental tasks may be of use to future studies.

Statistical analysis of the segment duration results revealed similar levels of variation across the three groups; however, diagrammatic representation demonstrated a trend towards increased intra-participant variation in duration of contact in the group with PD. Given the small participant numbers in the study and the resultant low power of the statistical tests, the lack of significant findings should not be over-interpreted. Previous studies have reported that segment durations, as measured by EPG, are more commonly affected than tongue-palate contact patterns in dysarthric speakers (Gibbon, Murdoch, Hardcastle, Theodoros, & Cahill, 2000; Murdoch, Gardiner, & Theodoros, 2000). This finding is consistent with the view that temporal instability is a sign of impairment to the motor

system (Ziegler et al., 1993). The present results of similar levels of intra-participant variation in tongue-palate contact patterns but a trend towards increased variation in segment durations indicate that the pattern of tongue-palate contact generally remains the same across repeated trials of an utterance; however, that segment durations may be more susceptible to fluctuations within the motor system. Further examination of across-trial variation in tongue-palate contact duration with increased participant numbers would be of interest in future studies.

In conclusion, the current investigation found no significant evidence of increased intra-participant variation in tongue-palate contact patterns or their durations across the three groups. Furthermore, there was no indication of any age-effects resulting in increased variation. The lack of significant findings in the present study may have resulted from a number of factors including; the mild-moderate nature of the articulatory impairment in the group with PD, the repetitive nature of the assessment task, the limited repertoire of consonants investigated, and the small numbers of participants in the groups studied. The findings of the durational analyses were of interest, indicating a trend towards increased across-trial variation in the group with PD. Studies incorporating increased participant numbers in the analysis of intra-participant variation in consonant duration would be of benefit to further elucidate the nature of temporal articulatory variation in PD.

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Note

1. *Tarp*: Short form of tarpaulin; *Sarge*: Short form of sergeant; *Lark*: A singing bird or a merry adventure/prank (colloquial).

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Appendix 1

Worked examples of the calculation of the absolute (AVI) and relative (RVI) variability indices (Farnetani & Provaglio, 1991) from an individual representative frame (IRF) of /t/ production. Electrode activation values of 0 and 100% are deemed invariant and are excluded from calculations. If an electrode is activated on 10% or 90% of occasions

this indicates a similar level of variability, therefore, for percentage activation of <50% scores are summed from zero and for percentage activation of >50% scores are summed from 100 to result in an overall score of 10 for both percentage values. Similarly, if an electrode is activated on 20 or 80% of occasions a similar level of variability results resulting in a score of 20 for both percentage activation values.

	100	100	100	100	100	100	
100	100	100	80	100	100	100	100
100	100	70	20	30	60	90	100
100	30	0	0	0	0	10	100
100	10	0	0	0	0	0	100
100	0	0	0	0	0	0	100
100	0	0	0	0	0	0	100
100	0	0	0	0	0	0	100

$$\text{Absolute Variability Index} = \frac{(3 \times 10) + (2 \times 20) + (3 \times 30) + (1 \times 40)}{62}$$

$$= \frac{200}{62}$$

$$= 3.23$$

$$\text{Relative Variability Index} = \frac{(3 \times 10) + (2 \times 20) + (3 \times 30) + (1 \times 40)}{35}$$

$$= \frac{200}{35}$$

$$= 5.71$$

Appendix 2

Individual and mean group results for the absolute and relative variability indexes (AVI and RVI) and

the coefficient of variation (CV) of total consonant duration.

Participant	AVI			RVI			CV duration		
	/t/	/s/	/l/	/t/	/s/	/l/	/t/	/s/	/l/
PD1	3.71	2.74	7.74	7.19	6.80	14.55	.17	.33	.42
PD2	5.48	2.42	8.23	8.95	6.82	20.40	.48	.27	-
PD3	6.48	7.74	8.98	8.55	11.16	13.59	.10	.34	.41
PD4	5.16	4.84	4.03	8.42	7.69	7.14	.30	.22	.10
PD5	3.87	4.68	4.68	7.50	8.53	9.06	.08	.28	.11
PD6	5.32	3.71	4.84	7.67	7.93	10.00	.21	.31	.22
PD7	5.65	3.87	6.77	7.00	6.49	12.00	.14	.66	.14
PD8	3.23	2.42	7.26	5.56	6.82	15.00	.12	.43	.15
Mean	4.86	4.05	6.57	7.61	7.78	12.72	.20	.36	.22
SD	1.13	1.77	1.83	1.08	1.53	4.15	.13	.14	.14
AC1	8.23	3.87	5.81	11.59	7.06	11.61	.27	.20	.25
AC2	6.13	3.71	9.35	8.44	7.19	15.26	.10	.30	.28
AC3	5.65	2.90	8.06	11.67	6.92	13.89	.11	.38	.09
AC4	3.55	3.87	2.26	7.10	9.23	7.78	.09	.35	.16
AC5	4.19	3.39	5.00	6.50	7.78	9.12	.06	.46	.24
AC6	2.42	2.90	1.61	4.41	8.18	4.55	.06	.14	.01
AC7	6.13	1.61	8.55	9.74	3.23	17.10	.12	.22	.20
Mean	5.19	3.18	5.81	8.49	7.08	11.33	.12	.29	.17
SD	1.94	.81	3.06	2.70	1.88	4.45	.07	.11	.10
YC1	2.58	4.03	3.87	3.64	8.33	7.27	.20	.27	.10
YC2	3.39	3.87	7.90	5.25	7.50	13.61	.11	.18	.17
YC3	7.58	4.19	4.19	11.75	8.39	7.88	.07	.13	.17
YC4	5.16	3.06	4.19	8.65	5.59	10.83	.11	.33	.25
YC5	6.77	2.26	10.81	10.50	4.24	18.61	.14	.23	.14
YC6	3.23	2.42	5.81	5.71	6.82	15.00	.16	.29	.10
YC7	6.77	4.19	5.32	10.50	8.13	10.00	.12	.18	.08
YC8	6.61	3.06	6.94	9.32	5.59	11.62	.11	.44	.14
Mean	5.26	3.39	6.13	8.17	6.82	11.85	.13	.26	.14
SD	1.95	.79	2.36	2.94	1.54	3.78	.04	.10	.05

Note: PD=participant with Parkinson's disease, AC=aged control participant, YC=young control participant, SD=group standard deviation.