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Speech production in Parkinson's disease: II. Acoustic and electropalatographic investigation of sentence, word and segment durations

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Abstract

Previous investigations employing electropalatography (EPG) have identified articulatory timing deficits in individuals with acquired dysarthria. However, this technology is yet to be applied to the articulatory timing disturbance present in Parkinson's disease (PD). As a result, the current investigation aimed to use EPG to comprehensively examine the temporal aspects of articulation in a group of nine individuals with PD at sentence, word and segment level. This investigation followed on from a prior study (McAuliffe, Ward and Murdoch) and similarly, aimed to compare the results of the participants with PD to a group of aged (n=7) and young controls (n=8) to determine if ageing contributed to any articulatory timing deficits observed. Participants were required to read aloud the phrase "I saw a ___ today" with the EPG palate in-situ. Target words included the consonants /l/, /s/ and /t/ in initial position in both the /i/ and /a/ vowel environments. Perceptual investigation of speech rate was conducted in addition to objective measurement of sentence, word and segment duration. Segment durations included the total segment length and duration of the approach, closure/constriction and release phases of EPG consonant production. Results of the present study revealed impaired speech rate, perceptually, in the group with PD. However, this was not confirmed objectively. Electropalatographic investigation of segment durations indicated that, in general, the group with PD demonstrated segment durations consistent with the control groups. Only one significant difference was noted, with the group with PD exhibiting significantly increased duration of the release phase for /la/ when compared to both the control groups. It is, therefore, possible that EPG failed to detect lingual movement impairment as it does not measure the complete tongue movement towards and away from the hard palate. Furthermore, the contribution of individual variation to the present findings should not be overlooked.

Keywords: *Parkinson's disease, electropalatography, acoustic analysis, durations*

Introduction

Impaired speech rate and segment durations have previously been identified in the speech of individuals with PD using both perceptual and instrumental means of assessment

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(Canter, 1963; Darley, Aronson, & Brown, 1969; Van Lancker, & Canter, 1981; Ludlow, & Bassich, 1984; Weismer, 1984; Chenery, Murdoch, & Ingram, 1988; Hammen, Yorkston, & Beukelman, 1989 ; Volkmann, Hefter, Lange, & Freund, 1992; Adams, 1994; Tjaden, 2000; Nishio, & Niimi, 2001; McRae, Tjaden, & Schoonings, 2002). The reasons for impaired speech rate in individuals with PD, whether a fast or slow rate of speech has been observed, are not salient (Weismer, Jeng, Laures, Kent, & Kent, 2001). As a result, studies of speech rate and segment durations in PD are required, using a number of different kinematic approaches, to further elucidate the underlying causes of these disturbances in individuals with PD.

Currently, a paucity of kinematic data exists describing lingual movement in individuals with PD. Investigations to date have employed case study designs and examined lingual movements in one or two participants with PD only (Hirose, Kiritani, & Sawashima, 1982; Ackermann, Grone, Hoch, & Schonle, 1993). Hirose et al. (1982) used X-ray microbeam to investigate lingual movement in two individuals with PD undertaking a syllable repetition task. The authors reported inconsistent velocity of lingual movement in the participants with PD as evidenced by high standard deviation values from the task.

Ackermann et al. (1993) used electromagnetic articulography (EMA) to examine the lingual kinematics of a woman with PD who exhibited dysarthria characterised by speech freezing during rapid syllable repetition tasks (i.e., a continuous /a/ sound was produced instead of the required consonant-vowel sequence during syllable repetition). Results of the investigation revealed that during repetition of the consonant-vowel sequence /ta/ the patient occasionally producing a continuous /a/ instead of the required /ta/ (Ackermann et al., 1993). During the periods of speech freezing it was noted that the participant's tongue tip movement occurred at reduced amplitude. Furthermore, that this reduced amplitude of tongue tip movement occurred concurrent with a considerably increased frequency of tongue movement (i.e., faster tongue tip movement) (Ackermann et al., 1993). Ackermann et al. (1993) stated that at a high rate of speech tempo the participant reduced the movement amplitude resulting in undershoot of the articulatory gesture (Ackermann, & Ziegler, 1991). Subsequently, occlusion for the plosive /t/ was not reached and a sustained /a/ vocalisation was produced as a result of an underlying hastening of articulatory movements (Ackermann et al., 1993). It can be seen, therefore, that these investigations have provided valuable contributions to our understanding of lingual movement disturbances in PD. However, studies are required using increased participant numbers to further our understanding of the mechanisms of lingual movement in individuals with PD.

As PD occurs in the mid-to-late stages of life (Hurtig, 2000), the impact of ageing upon speech production must also be considered (Weismer, 1984; Liss, Weismer, & Rosenbek, 1990). Limited studies have investigated the impact of ageing upon tongue movements. A previous investigation employed ultrasound to measure changes in lingual motor skills with advancing age and reported that ageing does result in significant decreases in lingual motor skill (Koshino, Hirai, Ishijima, & Ikeda, 1997). However, a recent study by Flanagan and Dembowski (2002) used X-ray microbeam instrumentation to investigate the relationship between speed of movement of the articulators, their range of motion and syllable rate during diadochokinesis tasks. The investigation employed two participant groups, one of 52 younger adults (aged 18 to 36 years) and another of 24 aged adults (ranging in age from 46 to 86 years) and reported that while syllable repetition rates were affected in ageing, the speed of articulator movement was comparable in the young and older participant groups (Flanagan, & Dembowski, 2002). The results of Flanagan and Dembowski (2002) provided initial evidence to suggest that ageing does not adversely affect the speed of

articulator movement. However, studies are required to determine whether the impaired lingual movements observed previously in individuals with PD (Hirose et al., 1982; Ackermann et al., 1993) can be explained by the disease process alone or whether it is partially influence by ageing of the speech-motor system.

One kinematic assessment technique that is yet to be explored in the examination of lingual movement in PD is electropalatography (EPG). Electropalatography is a non-invasive means of assessment capable of examining the duration of selected segments of consonant production (Morgan Barry, 1993; Goozee, Murdoch, & Theodoros, 1999; Gibbon, Murdoch, Hardcastle, Theodoros, & Cahill, 2000). It provides objective measurement of the approach, closure/constriction and release phases of the articulation of sound segments (Goozee et al., 1999). Investigations undertaken to date into segment durations in adults with acquired dysarthria have noted deficits in some or all of the aspects of lingual movement measured by EPG. It is, therefore, likely that EPG could provide useful information regarding the lingual movement deficit present in PD and potentially further the body of knowledge that currently exists regarding lingual movement in PD.

As a result, the present investigation aims to use EPG to comprehensively examine articulation at the sentence, word and segment level in a group of participants with PD. If lingual movement disturbances are found, this investigation aims to determine if these disturbances resulted from the pathology of PD or the combined result of both ageing and the pathology of PD. It is hypothesised that lingual movement deficits will be found in the participant group with PD. Furthermore, it is thought that age effects will contribute to any deficit noted.

Method

Participants

The present investigation employed the same three groups of participants as detailed in McAuliffe, Ward, and Murdoch (in press). These groups included nine individuals with PD who exhibited dysarthria characterised by consonant imprecision, seven aged controls and eight young controls. For specific details of the participants involved in the study, including inclusion/exclusion criteria, see McAuliffe et al. (in press).

Procedure

All participants were examined using perceptual and electropalatographic measures of speech function. The perceptual evaluation included judgement of the rate components of a speech sample by two speech-language pathologists (FitzGerald, Murdoch, & Chenery, 1987) and the rate section of the ASSIDS (Yorkston, & Beukelman, 1981). Specifically, measures of general rate, maintenance of rate, fluctuation of rate, prolonged intervals and short rushes of speech were taken from the speech sample. Inter-judge and intra-judge reliability were calculated using Spearman's rho correlations. Results revealed a high degree of inter-judge reliability ($rho = .979$, $p < .001$) and a high degree of intra-judge reliability for both judge one ($rho = .994$, $p < .001$) and judge two ($rho = .932$, $p < .001$). Only the words per minute (WPM) parameter from the ASSIDS was included.

Instrumental assessment was conducted using EPG. Participants were required to read aloud the phrase "I saw a ___ today" with an artificial palate in-situ. Target phonemes included the alveolar fricative /s/, lateral approximant /l/ and the alveolar stop /t/. These were examined in both the /i/ and /a/ vowel environment. The complete EPG assessment procedure employed in the current study is detailed in McAuliffe et al. (in press).

Instrumental data analysis

Acoustic analysis of sentence and word durations. Each EPG and associated acoustic file was saved to CD-ROM for analysis. The acoustic files were then extracted and used in the analysis of sentence and word durations. The acoustic analysis program Sound Forge (1997–2001) version 5.0, a commercially available acoustic program, was used to complete the sentence and word duration analysis. Each acoustic file was opened in the program and the waveform displayed. The sentence employed was "I saw a ____ today". Therefore, sentence length was measured from the beginning of the acoustic signal in "I" to the end of the acoustic signal in the word "today" for each sentence of each participant in the investigation. Word duration was measured for each word from the end of the acoustic signal in "a" to the beginning of the stop gap for the /t/ in "today". In instances where word boundaries were difficult to distinguish from the acoustic trace, the auditory signal was used to determine the beginning or end point of a word. For reliability purposes, 5% of the sentence and word duration data sample (184 of 3671 traces) were recalculated and a t-test for related measures performed on the resultant data. Results revealed similar scores for sentence ($t=1.116$, $p=.267$) and word ($t=1.121$, $p=.272$) duration, therefore, reliability of durational measures was assumed.

EPG segment timing analysis. Segment durations were analysed in the data analysis program EPGLAB (Scott, & Goozee, 2002). The EPGLAB program uses totals displays in its data analysis. Totals displays graph the number of activated electrodes in a region of the palate as a function of time (Hardcastle, Gibbon, & Nicolaidis, 1991) and are important tools with which to explore the temporal aspects of lingual activity. The totals displays generated were divided into the anterior and posterior zones of the palate. For all consonants the number of contacted electrodes in the anterior zone of the palate (or first four rows of the artificial palate) were displayed. Figure 1 contains a diagrammatic representation of a totals display similar to those used in the EPGLAB program.

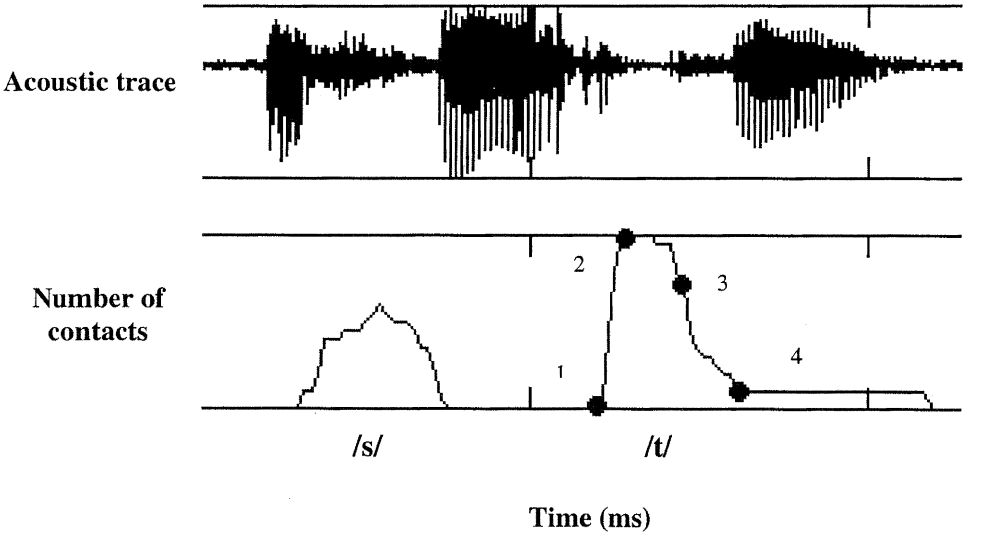

Figure 1. Diagrammatic representation of a totals display as used in the present study. The utterance pictured is "I saw a tea". 1=onset of the approach to /t/, 2=onset of closure for /t/, 3=onset of release of /t/, and 4=end of the release.

Table I. Annotation points used in EPG articulatory timing data analysis.

Consonant	(1) Onset of Approach	(2) Onset of Closure/ Constriction	(3) Onset of Release	(4) End of Release
/t/	Frame immediately before the number of contacted electrodes began to increase.	First frame that demonstrated a complete anterior seal in the anterior zone of the palate.	Final frame that exhibited a complete anterior seal in the anterior zone of the palate.	Frame that immediately followed a steady decline in the number of contacted electrodes and the beginning of stable contact for the following vowel.
/l/	As above.	First frame that exhibited at least four central electrodes contacted in the anterior zone of the palate.	Final frame that exhibited at least four central contacted electrodes in the anterior zone of the palate.	As above.
/s/	As above.	First frame that demonstrated a number of contacted electrodes that were 10% less than the number of contacted electrodes at the frame of maximum contact (e.g., if 23 electrodes were contacted at the frame of maximum contact, 10% would equal two electrodes, therefore, the first frame that exhibited 21 contacted electrodes would be considered the first frame of constriction).	Final frame that exhibited a number of contacted electrodes that was within a 10% window of the number of contacted electrodes at the frame of maximum contact (e.g., if 23 electrodes were contacted at the frame of maximum contact, the final frame that exhibited 21 electrodes contacted would be the onset of release).	As above.

Four specific annotation points across the totals display were used to measure three phases of consonant production including, (i) the *approach phase* in which the tongue moves to form a pattern of closure on the palate for stops, or a point of stable constriction for fricatives (between annotation points 1 and 2), (ii) the *closure or stable constriction phase* (between annotation points 2 and 3) and (iii) the *release phase* of the consonant in which the tongue moves from its position on the palate to its position for the subsequent sound. Mean durations of the approach, closure/constriction and release phase of consonant production were calculated for each participant's ten repetitions of the target consonants. Table I contains the annotation points employed in the current data analysis. The annotation points noted in Table I correspond to the numbers represented in the totals display (Figure 1).

Results

Statistical analysis was undertaken using non-parametric statistics. For the speech sample results, the use of ordinal data necessitated the use of such statistics. However, comparisons across EPG results for sentence, word and segment duration were undertaken using non-parametric statistics due to violation of the assumption of homogeneity of variance across

Table II. Mean results and comparison between the participants with Parkinson's disease (PD) (n=9), aged control (AC) participants (n=7), and young control (YC) participants (n=8) on speech rate parameters from the perceptual rating scale of FitzGerald, Murdoch, and Chenery (1987).

	PD Group		AC Group		YC Group			
Parameter	Mean	SD	Mean	SD	Mean	SD	χ^2	*p*
General Rate	4.78	1.20	4.13	0.35	4.13	0.35	3.19	0.203
Maintenance of Rate	4.44	0.73	4.00	0.00	4.00	0.00	5.98	0.055
Fluctuations in Rate	1.56	0.73	1.00	0.00	1.00	0.00	8.08	0.018*
Prolonged Intervals	1.22	0.44	1.00	0.00	1.00	0.00	3.71	0.156
Short Rushes of Speech	2.78	1.56	1.13	0.35	1.00	0.00	11.29	0.004**

Note: *=p≤0.05, **=p≤0.01. SD=standard deviation.

all parameters (Levene's statistic; p<.05) and the presence of unequal group sizes. As a result, the Kruskal-Wallis one-way analysis of variance procedure was completed for comparisons across the three participant groups and post-hoc analysis was undertaken using Mann-Whitney U statistical tests.

Perceptual assessment results

Speech sample analysis results. The group mean and standard deviation scores on the parameters of speech rate are shown in Table II. A Kruskal-Wallis one-way analysis of variance procedure revealed a significant difference between the three participant groups for the parameters of short rushes of speech (p<.01) and fluctuations in rate (p<.05). A trend towards a significant difference (p=.055) between the three groups was demonstrated for maintenance of rate. No other significant differences were found.

Post-hoc analysis (at p<.05) revealed a significant increase in the presence of short rushes of speech in the participants with PD when compared to both the AC (U=13.50, p=.027) and YC (U=12.00, p=.021) participant groups. Similar levels of short rushes of speech were found when the AC and YC group scores were compared (U=28.00, p=.721). On the parameter of fluctuations in rate a significant increase in fluctuations of rate was demonstrated in the participant group with PD when compared to both the AC (U=20.00, p=.038) and YC groups (U=20.00, p=.038). Similar levels of fluctuations in rate were demonstrated by the AC and YC groups (U=32.00, p=1.00).

While no significant differences were found between the three participant groups for the parameter of general rate, six of the nine participants with PD (66.67%) demonstrated impaired rate on the speech sample task. One participant demonstrated a slowing of rate to a mild degree; however, five participants with deviant rates of speech exhibited an increased rate. Three exhibited a mild increase in rate of speech, one a moderate increase and another participant a severely increased rate of speech. In addition, short rushes of speech were also demonstrated by 66.67% of the group with PD. The results of individual participants on the perceptual ratings of speech rate are shown in Table III.

Assessment of intelligibility results (rate only). The participant group with PD recorded a mean WPM on the ASSIDS of 213.13 (SD=28.21). The AC participant group demonstrated a mean WPM of 216.96 (SD=22.52) and the YC participant group a

Table III. Individual results of the participants with Parkinson's disease (n=9) on the rate parameters of the rating scale of FitzGerald, Murdoch and Chenery (1987).

Participant	General Rate	Maintenance of Rate	Fluctuations of Rate	Prolonged Intervals	Short Rushes of Speech
1	4	4	1	1	1
2	7	6	1	1	5
3	3	5	2	2	3
4	6	4	1	1	5
5	4	4	1	1	1
6	5	4	3	2	3
7	4	4	1	1	1
8	5	5	2	1	3
9	5	4	2	1	3

Note: For the parameters of general rate and maintenance of rate a seven-point rating scale was employed. 1=excessively slow rate of speech or excessive reduction in rate towards the end of a segment, 2=moderately slow rate of speech or moderate reduction in rate towards the end of a segment, 3=just noticeable slow rate of speech or reduction in rate towards the end of a segment, 4=normal rate or normal maintenance of rate, 5=just noticeable increase in rate or increase in rate towards the end of a segment, 6=moderate increase in rate or moderate increase in rate toward the end of a segment, and 7=excessively fast rate or an excessive increase in rate toward the end of a segment. On the parameters of fluctuations of rate, prolonged intervals, and short rushes of speech a five-point rating scale was employed. 1=absence of deviant speech feature, 2=seldom presentation of deviant speech feature, 3=occasional presentation of deviant speech feature, 4=often presentation of deviant speech feature, and 5=frequent presentation of deviant speech feature.

mean WPM of 221.96 (SD=33.08). A Kruskal-Wallis one-way analysis of variance revealed no significant difference between the three groups on the parameter of WPM (χ^2=.828, p=.661).

Acoustic and electropalatographic assessment results

Following initial screening of the electropalatographic data set, 29 files were excluded from data analysis as they were either corrupted during data collection or a participant had said the word incorrectly during the assessment (these errors had gone unnoticed during the process of data collection). The unanalysable files accounted for 1.5% of the total EPG data set and were also removed from the perceptual EPG analysis. Twenty-five of the corrupted files belonged to participant three in the group with PD. As participant three was unavailable for re-assessment his remaining files (68% of his EPG data set) were analysed. In addition, the EPG palate of participant 10 demonstrated a faulty electrode in its most posterior row. Therefore, on occasions where an electrode was contacted anterior to the faulty electrode the faulty electrode was assumed concurrently activated. Furthermore, the sentence and word durations of participant four (a 73 year-old man with PD) were excluded from data analysis as this participant read the sentence "I saw a ____". Hence, his sentence durations and word durations could not be compared to other participants. However, his segment durations were included in the data set.

Sentence duration results. Table IV contains the mean scores of the three participant groups for sentence duration. Statistical examination using the Kruskal-Wallis one-way analysis of variance procedure revealed no significant differences (p>.05) between the three groups for sentence duration in the six different word conditions.

Table IV. Sentence durations (in seconds) and results of the Kruskal-Wallis statistical examination across the participants with Parkinson's disease (PD) (n=8), aged control participants (AC) (n=7) and young control participants (YC) (n=8) in the repetition of the sentence "I saw a ____ today".

	PD Group		AC Group		YC Group			
Word	Mean	SD	Mean	SD	Mean	SD	χ^2	*p*
Leap	1.374	0.344	1.445	0.243	1.380	0.140	0.552	0.759
Lark	1.370	0.289	1.490	0.277	1.439	0.149	0.650	0.722
Sea	1.395	0.353	1.386	0.239	1.392	0.145	0.022	0.989
sarge	1.392	0.316	1.487	0.210	1.559	0.154	1.484	0.476
Tea	1.387	0.332	1.350	0.229	1.357	0.136	0.006	0.997
Tarp	1.392	0.305	1.432	0.228	1.450	0.147	0.049	0.976

Note: SD=standard deviation,

Word duration results. The group mean scores for word duration are located in Table V. A Kruskal-Wallis one-way analysis of variance revealed no significant differences ($p>.05$) between the three groups on any of the six word conditions.

Segment duration results

Table VI contains the group mean scores for the mean duration of the approach, closure/constriction, release and total length of contact phases for the three participant groups. Given the number of statistical comparisons undertaken, examination was completed using the Kruskal-Wallis one-way analysis of variance with a significance level of $p<.01$ (Shearer, 1982). Results revealed a significant difference between the three groups for the release phase of /la/ only ($p<.01$) (see Table VI). Post hoc comparisons revealed that the participant group with PD demonstrated a significantly increased duration of the release of /la/ when compared to both the AC ($U=.00$, $p=.001$) and YC ($U=3.00$, $p=.002$) control groups, while the AC and YC groups demonstrated similar durations for the release of /la/ ($U=24.00$, $p=.694$).

Discussion

The results of the present investigation revealed that the participants with PD, as a group, were perceived to exhibit similar general rates of speech, maintenance of rate and

Table V. Word durations (in seconds) and results of the Kruskal-Wallis statistical examination across the participants with Parkinson's disease (PD) (n=8), aged control participants (AC) (n=7) and young control participants (YC) (n=8).

	PD Group		AC Group		YC Group			
Word	Mean	SD	Mean	SD	Mean	SD	χ^2	*p*
leap	0.263	0.065	0.261	0.072	0.321	0.080	2.620	0.270
lark	0.330	0.103	0.316	0.081	0.366	0.053	1.723	0.422
sea	0.355	0.090	0.359	0.057	0.351	0.052	0.017	0.992
sarge	0.492	0.119	0.521	0.087	0.513	0.067	0.150	0.928
tea	0.351	0.084	0.333	0.054	0.342	0.046	0.178	0.915
tarp	0.392	0.090	0.408	0.073	0.392	0.053	0.286	0.867

Note: SD=standard deviation.

Table VI. Comparison of the mean segment durations in milliseconds (ms) across the participant group with Parkinson's disease (PD) (n=9 in the /i/ vowel environment, n=8 in the /a/ vowel environment), aged control participants (AC) (n=7) and young control participants (YC) (n=8).

	PD Group		AC Group		YC Group			
Cons. Vow.	Mean	SD	Mean	SD	Mean	SD	χ^2	p
/li/								
Approach	36.00	13.49	30.43	13.94	24.75	8.83	3.60	0.165
Closure	68.67	20.43	82.71	14.93	89.75	22.56	3.63	0.163
Release	42.11	10.25	34.43	10.31	29.75	10.98	4.41	0.110
Total	146.56	32.93	147.57	19.93	144.25	22.53	0.10	0.951
/la/								
Approach	37.71	19.34	27.86	13.11	20.88	6.58	5.39	0.068
Closure	68.43	19.92	72.57	12.74	82.88	17.74	1.80	0.406
Release	44.29	15.60	25.71	5.38	23.13	8.74	12.26	0.002**
Total	150.25	38.06	126.14	14.52	126.87	17.28	2.52	0.283
/si/								
Approach	92.67	25.72	76.71	14.12	92.25	17.19	1.65	0.439
Constric.	99.78	31.06	105.29	17.70	98.13	24.49	0.54	0.762
Release	68.56	9.22	67.43	11.09	84.50	13.42	6.48	0.039
Total	261.00	51.30	249.43	33.59	274.87	36.85	1.89	0.388
/sa/								
Approach	83.25	18.76	70.86	20.64	79.63	11.34	1.26	0.533
Constric.	65.50	13.65	71.57	12.35	80.25	21.33	3.32	0.190
Release	74.13	16.40	65.29	16.90	58.63	5.83	4.04	0.133
Total	222.88	49.60	207.71	32.46	218.50	22.05	0.87	0.649
/ti/								
Approach	53.11	20.61	37.00	14.21	34.38	11.56	5.34	0.069
Closure	86.78	28.60	87.00	13.06	75.63	19.66	1.55	0.460
Release	64.11	10.08	74.14	6.94	81.12	17.34	5.90	0.052
Total	204.00	35.70	198.14	22.55	191.13	24.04	0.74	0.690
/ta/								
Approach	49.50	17.53	32.71	14.53	30.88	9.40	6.72	0.035
Closure	70.50	22.65	82.71	14.91	73.25	18.10	1.90	0.387
Release	73.13	25.81	48.43	14.39	54.88	19.05	4.93	0.085
Total	194.13	45.54	163.86	22.73	159.00	23.07	3.20	0.202

Note: **=$p \leq 0.01$. Cons. Vow=consonant-vowel sequence, Constric.=duration of tongue constriction on the palate during the production of an alveolar fricative, SD=standard deviation.

prolonged intervals during the paragraph reading task as both the aged and young control groups. Short rushes of speech and fluctuations in rate were, however, perceived in the speech of the group with PD and were not present in the speech samples of the aged and young control speakers. Examination of the results of individual participants revealed impaired rate in the participant group with PD. In particular, general rate was impaired in six of the nine participants with PD, underscoring the variability of speech rate present in the participant group.

The perception of disturbed rate and the presence of short rushes of speech and fluctuations in rate in the participant group with PD were not confirmed objectively through either the ASSIDS or acoustic analysis of sentence and word duration in the present investigation. The participant group with PD demonstrated a similar WPM to both the aged and young control groups on the ASSIDS. In addition, they demonstrated similar

sentence and word durations to both the aged and young control participants following acoustic measurement.

At the segment level, the current study revealed similar durations across the three groups. Only one exception to this was noted, with the participant group with PD demonstrating significantly increased duration of the release phase of /la/ when compared to both the aged and young control groups. The results of the present investigation will be discussed in two sections, rate of speech (including sentence and word durations) and segment durations.

Rate of speech (including sentence and word durations)

As a group, the participants with PD demonstrated similar general rates of speech, maintenance of rate and prolonged intervals in the passage-reading task to both the aged and young control participants. However, observation of individual participant scores on the passage-reading task revealed the presence of rate disturbance in the participants with PD. Six of the nine participants with PD demonstrated rate disturbances to varying degrees. In addition, the participant group with PD was perceived to exhibit short rushes of speech in the passage-reading task. Six of the nine participants with PD demonstrated short rushes of speech in their speech sample, all of whom exhibited either occasional or frequent short rushes of speech. Furthermore, fluctuations in rate were also noted in the participant group with PD with four of the nine participants exhibiting this deviant speech production feature (see Table III).

These perceptual observations were not confirmed using objective rate measures. The participants with PD demonstrated a similar number of words spoken per minute to both the aged and young control speakers on the ASSIDS. In addition, the acoustic measurement of sentence and word durations revealed similar durations across the three groups for all sentences and words. This finding was consistent with previous objective investigations of sentence duration that have reported similar sentence durations between individuals with PD and control speakers in passage and sentence reading tasks (Canter, 1963; Ludlow, & Bassich, 1984) and similar levels of syllables spoken per minute in sentence reading tasks (Ackermann, & Ziegler, 1991) . However, the results of the present study conflict with previous investigations that have reported both increased (Weismer, 1984; Hammen et al., 1989; Adams, 1994; Tjaden, 2000) and decreased (Nishio, & Niimi, 2001) rates of speech in individuals with PD.

Interestingly, the present investigation reported no difference in rate between the young control participants and either of the aged participant groups. This was in contrast to the often observed 'slowing' of speech rate with increased age (Meyerson, 1976; Ramig, 1983; Amerman, & Parnell, 1992). It is possible that the nature of the assessment task (reading of sentences) resulted in similar speech rates between the groups. Furthermore, as slower rates of speech are expected from aged individuals, judges may perceive aged participants speech rate as normal, even if it would be considered slow compared to younger speakers (Weismer, 1984).

The nature of the speech tasks themselves may somewhat explain the conflict in the findings of the present investigation. In fact, given the differing natures of the assessment tasks it is possibly hazardous to compare their results. The passage-reading task, while still a controlled laboratory task, involved the reading of multiple sentences which included pauses. In contrast, the ASSIDS and sentence and word durations were calculated from a sentence reading task only, and pauses would, therefore, have been limited in the ASSIDS

and absent in the sentence repetition tasks. Pauses are thought to influence a judge's perception of rate (Tjaden, 2000) and the presence of pauses in the passage reading task may have led to the perception of rate disturbance in the participants with PD. The absence of pauses in the more objective measures of rate may explain the difference in findings.

It is possible that the small participant numbers in the present study played a part in the present findings; however, it is more likely that the nature of the EPG task itself contributed to the findings. The short sentence employed in the EPG assessment procedure may not have been a long enough, or natural enough, sample to elicit the rate disturbance noted in the passage-reading task. This was consistent with the results of Ludlow and Bassich (1984) who also stated that their findings of normal speech rate in a group of 12 individuals with PD may have been related to the short sentence reading task employed. The authors, in referring to the findings of increased and decreased speech rates in other investigations into speech production in PD, stated that "perhaps, speech imitation or production tasks do not elicit this symptom, while oral reading and conversational speech do" (Ludlow, & Bassich, 1984, p. 173). Furthermore, both articulation time and pause time are a function of rate of speech (Linebaugh, & Wolfe, 1984). As inter-word pauses were not measured in the present study, it is possible that increased duration of inter-word pauses and decreased articulation rate resulted in normal speech rate in the participants with PD. However, more thorough acoustic investigations would be required to substantiate such a claim.

The conflict in findings between judges' perceptions of speech rate and physical measures of rate found in the present investigation has been reported previously (Kent, & Rosenbek, 1982; Weismer, 1984; Tjaden, 2000; Torp, & Hammen, 2000;). Various reasons have been postulated for the perception of increased speech rate in the presence of normal speech rate. A judge's perception of rate is influenced by a number of factors including the presence and length of pauses in the speech stream, the fundamental frequency of the individual's speech production and the amplitude of speech production (Tjaden, 2000). In addition, it is thought possible that blurring of acoustic contrasts (spirantisation of stop consonants) may also contribute to the differences between objective measures and perception of rate (Kent, & Rosenbek, 1982). Therefore, it is possible that the judges' ratings in the present investigations may have been influenced by the factors mentioned.

Weismer (1984) suggested that the perception of increased rate may be related to the judges' "expectations" of the speech rate of individuals they have perceived to be aged. Individuals with PD exhibit certain vocal characteristics associated with ageing (Weismer, 1984) and as aged individuals are known to exhibit reduced speech rate when compared to younger speakers (Ramig, 1983; Amerman, & Parnell, 1992) it is possible that the speakers with PD speak faster than the "expectation" of the perceptual judges (Weismer, 1984). While a significant difference was not found between the participants with PD and the aged controls for general rate of speech in the present study, investigation of individual scores highlighted the perceived rate abnormalities of the participant group with PD. However, in the present investigation both the aged and young participants demonstrated, in general, similarly unimpaired rates of speech. Hence, the "expectation" theory is unlikely to account for the results obtained in the present study.

Inter-participant variability may also have contributed to the lack of significant findings for rates of speech. Both increased and decreased rates of speech were observed perceptually in the participants with PD. However, given that the presence of reduced and increased rate in a participant group results in the achievement of normal rates of speech when group data is tabulated, it is possible that inter-participant variability

contributed to the results of the present study. Previous research has commented on the significant variability in speech rate that exists in speakers with PD (Ludlow, & Bassich, 1984; Metter, & Hanson, 1986; Hammen, Yorkston, & Minifie, 1994). In particular, previous investigations have noted that this may have contributed to the lack of significant findings in prior studies (Schulz, & Grant, 2000). It is, therefore, possible that variation in speech rate may have contributed to the lack of significant findings in the present investigation. Hence, future instrumental investigations may benefit from the division of participant groups based upon their rate of speech noted perceptually or objectively. It is possible that such a strategy may provide further insight into the underlying causes for rate disturbance in individuals with PD.

Segment durations

The results of the present investigation revealed that, in general, the participant group with PD demonstrated similar segment durations to the control groups. Previous acoustic investigations that have measured syllable and sound segment durations have also reported similar segment durations in participants with PD when compared to control participants (Tatsumi, Sasanuma, Hirose, & Kiritani, 1979; Ludlow, Connor, & Bassich, 1987; Connor, Abbs, Cole, & Gracco, 1989; Connor, Ludlow, & Schulz, 1989; Ackermann, & Ziegler, 1991). However, these results cannot be directly compared given the differing assessment techniques employed. To the investigator's knowledge, no study has yet investigated segment durations using EPG in participants with PD and, as a result, direct comparisons with current electropalatographic data cannot be undertaken.

On the basis of the perceptual findings of short rushes of speech, fluctuations in rate and increased general rate in some participants with PD it was expected that impaired segment durations would also be noted. However, this was not the case. Only one significant difference was found, with the participant group with PD demonstrating increased duration of the release phase for /la/ when compared to the control groups. The reasons for the largely comparable segment durations across the three groups in the presence of perceptual deficits is unknown. It is possible that the assessment technique of EPG failed to detect deviant segment timing as it did not measure the complete movement of the tongue from the neutral position to it's contact with the hard palate (the approach) and then the complete movement of the tongue back to the neutral position (the release). Investigation with electromagnetic articulography (EMA) may provide further insight into lingual movement impairment in PD. Furthermore, investigation is also required at case level to gain an understanding of the relationship of tongue movement to perceptual measures in specific individuals. It is possible that individual impairment existed, however, that this was obscured by the group analyses.

Conclusions and directions for further research

Overall, the present investigation revealed similar speech rate, maintenance of rate and prolonged intervals between the three participant groups. However, specific to general rate of speech, both an increased and decreased general rate was observed perceptually in the participants with PD when individual results were examined. Short rushes of speech and fluctuations of rate were also noted in the participants with PD. These results compared favourably with the clinical impression of increased and variable speech rates in PD (Duffy, 1995).

The perceptual observation of disturbed speech rate in the group with PD was not confirmed using objective measurements of speech rate. Similar numbers of words spoken per minute and similar sentence and word durations were revealed across the three groups. This result was also comparable with previous investigations that have noted normal rates of speech on objective testing in individuals with PD. The conflict in findings between the clinical perception of speech rate and physical measures of rate has been noted in previous investigations and it is possible that variability within the participant groups contributed to the lack of significant findings in the present investigation. In addition, the differing nature of the assessment tasks and the possible presence of increased inter-word pauses may have contributed to the results.

Investigations of segment duration, a finer level of analysis, revealed a pattern of similar segment durations across the three participant groups. This result was surprising given the speech rate impairments noted on perceptual investigation. It is possible that EPG failed to detect impaired segment durations as it does not measure the complete motion of tongue. Therefore, further investigation using EMA may be beneficial in the exploration of lingual movement deficits in PD.

The contribution of variation in speech rate in the participant group with PD to the present findings should also not be overlooked. Previous research has suggested that speech rate variability within groups with PD may have contributed to the lack of statistical significance in prior investigations (Schulz, & Grant, 2000). Therefore, future investigations may benefit from the division of participant groups with PD based upon their rate of speech. In particular, future kinematic investigations employing EPG and EMA may benefit from such an approach. Furthermore, given the individual participant variation noted in the present investigation, the need for case-based analysis of articulatory timing using EPG in participants with PD has been highlighted. Future studies may benefit from a case-based approach to a concurrent examination of both articulatory timing and the spatial features of articulatory contact.

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