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Speech production in Parkinson's disease: I. An electropalatographic investigation of tongue-palate contact patterns

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Abstract
Previous studies have indicated that consonant imprecision in Parkinson's disease (PD) may result from a reduction in the amplitude of lingual movements or articulatory undershoot. While this has been postulated, direct measurement of the tongue's contact with the hard palate during speech production has not been undertaken. Therefore, the present study aimed to use electropalatography (EPG) to determine the exact nature of tongue-palate contact in a group of individuals with PD and consonant imprecision (n=9). Furthermore, the current investigation also aimed to compare the results of the participants with PD to a group of aged (n=7) and young (n=8) control speakers to determine the relative contribution of ageing of the lingual musculature to any articulatory deficits noted. Participants were required to read aloud the phrase 'I saw a ___ today' with the artificial palate in-situ. Target words included the consonants /l/, /s/ and /t/ in initial position in both the /i/ and /a/ vowel environments. Phonetic transcription of phoneme productions and description of error types was completed. Furthermore, representative frames of contact were employed to describe the features of tongue-palate contact and to calculate spatial palatal indices. Results of the perceptual investigation revealed that perceived undershooting of articulatory targets distinguished the participant group with PD from the control groups. However, objective EPG assessment indicated that undershooting of the target consonant was not the cause of the perceived articulatory errors. It is, therefore, possible that reduced pressure of tongue contact with the hard palate, sub-lingual deficits or impaired articulatory timing resulted in the perceived undershooting of the target consonants.

Keywords: *Parkinson's disease, electropalatography, tongue-palate contact, articulation*

Introduction

Previous research has contended that imprecision of consonants evident on perceptual investigation and spirantisation noted on acoustic investigations of articulation in speakers with Parkinson's disease (PD) may result from the performance of articulatory movements

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at a reduced amplitude (Logemann, & Fisher, 1981; Weismer, 1984; Ackerman, & Ziegler, 1991). Moreover, that impaired production of stop consonants results from a failure of the tongue to enact complete oral closure (Logemann, & Fisher, 1981; Kent, & Rosenbek, 1982; Weismer, 1984; Ackermann and Ziegler, 1991; Ackermann, Hertrich, & Hehr, 1995). Researchers have hypothesised that in order to maintain a normal rate of speech, individuals with PD reduced the amplitude of articulatory movement resulting in the phenomenon termed ''articulatory undershoot'' (Kent, & Rosenbek, 1982).

While the concept of articulatory undershoot has been hypothesised, direct measurement of the tongue's contact with the hard palate during connected speech has not been undertaken. Through direct investigation of the tongue's contact with the hard palate, further information regarding the articulatory disorder present in the speech of individuals with PD could be obtained. In addition, the theory that the impaired articulation noted in speakers with PD results from incomplete closure of the tongue on the hard palate could be substantiated. One instrumental assessment technique capable of directly measuring the tongue's contact with the hard palate during speech production is electropalatography (EPG).

Electropalatography is able to record, in real time, tongue-palate contact patterns and lingual articulatory movement within the oral cavity (Hardcastle, Gibbon, & Jones, 1991). Such a technique has the potential to provide valuable insights into the articulatory and speech rate disturbance present in PD. Furthermore, as EPG directly measures the tongue's contact with the hard palate and the duration of this contact, the technique could quantitatively document the existence of the articulatory undershoot phenomena. Indeed, a recent study demonstrated that EPG was capable of quantifying the presence or absence of articulatory undershoot in adult-acquired dysarthria (Gibbon, Murdoch, Hardcastle, Theodoros, & Cahill, 2000). However, investigations are yet to employ EPG in the measurement of tongue-palate contact patterns in individuals with PD.

In the consideration of possible causes of speech production deficits in PD, the contribution of ageing should not be overlooked (Weismer, 1984). Impaired articulatory precision noted in PD has also been identified in the speech production of normally ageing adults (Ryan, & Burk, 1974; Amerman, & Parnell, 1982; Ramig, 1983; Parnell, & Amerman, 1987). Kahane (1981) reported that age-related changes to the orofacial musculature may result in measurable impacts upon articulation and speech intelligibility. As a result, studies are required to determine the relative contribution of ageing to the speech dysfunction noted in individuals with PD. To date, only a limited number of investigations into the speech production processes of individuals with PD have included both an aged control group and young control group for comparative purposes (Weismer, 1984; Ackermann, & Ziegler, 1991; Kleinow, Smith, & Ramig, 2001). These studies have been underscored by the premise that ageing may have contributed to a speech deficit if a significant difference reported to exist in young and aged controls was present, even stronger, in a comparison between the young controls and individuals with PD.

The present investigation aims to use EPG to determine the exact nature of tongue-palate contact patterns in individuals with PD and perceived consonant imprecision. Furthermore, this investigation aims to determine if the contact patterns of the individuals with PD differ significantly from those of aged individuals and young individuals. Two control groups have been included in the present investigation to determine if ageing has contributed to any articulatory disturbance observed in the group with PD.

Method

Participants

The participant group consisted of nine individuals, eight males and one female, diagnosed with PD by a qualified neurologist. The mean age of the group was 67.89 years (SD=8.12 years) with an age range of 57 to 83 years. Specific biographical and medical details of the participants with PD are located in Table I. Participants with PD were judged appropriate for participation in the study if they exhibited a dysarthria including consonant imprecision as determined by a speech pathologist. 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.

Two groups of neurologically unimpaired control participants were included for comparative purposes. Both an aged adult control group (AC) and a young adult control group (YC) were included. Each participant in these groups presented with perceptually normal speech as judged by a speech pathologist. The AC participant group consisted of seven males with a mean age of 67.71 years (SD=8.88 years) and an age range of 50 to 79 years. The YC group comprised one male and seven females (mean age=25.63 years, SD=2.67 years) ranging in age from 23 to 31 years. Participants were excluded from either control group if they exhibited any history of neurological disorder or disease, a history of speech disorder, surgery that involved the lips or tongue, drug and/or alcohol abuse or dementia.

Procedure

Both the participants with PD and the control participants underwent a series of perceptual and electropalatographic assessments. The perceptual assessment included the rating of a speech sample on the articulatory and overall intelligibility dimensions of a perceptual rating scale (FitzGerald, Murdoch, & Chenery, 1987) and an examination of the articulatory accuracy and articulatory characteristics of the EPG target consonants recorded during the electropalatographic assessments. The EPG assessment is described in detail below. Participants with PD were assessed in an "on" medication phase where possible. In general, assessment occurred in the morning to minimise the effects of fatigue.

Table I. Biographical and medical details of the nine participants with Parkinson's disease.

Participant	Gender	Age	Years post-onset	Medication	Hoehn & Yahr
1	M	67	8	Madopar, Sinemet	3.0
2	M	62	6	Sinemet	3.0
3	M	74	4	Sinemet, Comtan	2.0
4	M	73	6	Sinemet, Tazmar	3.0
5	F	83	16	Sinemet	2.0
6	M	63	3	Sinemet	3.0
7	M	61	8	Madopar, Comtan	3.0
8	M	71	5	Madopar	3.0
9	M	63	20	Sinemet, Art., Brom.	4.0

Note: Hoehn & Yahr=participants rating on the Parkinson's disease clinical disability scale (Hoehn & Yahr, 1967), Art.=Artane, Brom.=Bromocriptine.

Perceptual ratings

Speech sample analysis. All participants were judged by two qualified speech pathologists on the overall intelligibility and articulatory parameters of the perceptual speech dimensions (FitzGerald et al., 1987). These parameters were precision of consonants, phoneme length, precision of vowels and overall intelligibility. If the judges differed in their ratings for a particular parameter a further rating session was conducted. During this rating session both judges conferred to produce a single consensus rating for each dimension. It was this rating that was used in the analysis of the results. The judges' perceptual rating scores from all participants were compared using a Spearman's rho rank correlation. Results revealed a high degree of reliability between the two judges (rho=.996, $p<.001$). Examinations also revealed a high degree of intra-judge reliability with judge one obtaining a mean correlation coefficient of rho=.997, $p<.001$ and judge two demonstrating a mean correlation coefficient of rho=.995, $p<.001$.

Perceptual analysis of electropalatographic consonant productions. Analysis of each individual's perceptual output during the electropalatographic assessment was undertaken for all three participant groups. Initially, two speech pathologists independently judged each individual's target consonant production to determine if it was an accurate representation of the consonant or if it was produced in error. When the two judges disagreed on a rating a further rating session was conducted together and consensus agreement reached. A percentage of consonants produced in error was then calculated for each participant (for each of the six words).

Following initial error identification, two speech pathologists completed subsequent ratings to categorise each participant's error productions. During this session the two judges classified the errors according to a number of parameters. Both judges made independent judgements and were blind to the group allocation of the participants. A similar phonetic analysis to that of Logemann and Fisher (1981) was undertaken and the errors were firstly classified according to their phonetic features. The presence or absence of voicing, place of articulation and manner of articulation were noted. In addition, a parameter termed "other" was also considered. It contained the following descriptive terms: lateralised, undershot, and overshot. Lateralised referred to the perception of lateral air escape (particularly for the production of fricative sounds). The term "undershot" referred to the perception, on behalf of the judges, that the tongue did not make appropriate contact with the hard palate (i.e., the tongue did not achieve complete contact on the palate or this contact was less than that required for a perceptually normal production). The term "overshot" was the opposite of undershot. It referred to the perception, by the judges, that the tongue was increased in its contact with the hard palate during production of the consonant (i.e. more of the area of the tongue contacted the hard palate than would generally be expected during perceptually normal consonant production). The error type was also investigated and the judges classified the errors of the participants as errors of omission, substitution or distortion. In cases of a very mild pronunciation error, no changes to voicing, placement or manner of production were noted; however, a noticeable deviation or distortion from the correct production had occurred. In such instances, the error was termed distortion only. Where discrepancies were noted in the two judges' ratings a consensus rating was completed using a third judge. The consensus rating is reported. Unlimited repetitions of each participant's consonant productions were allowed during the rating procedure.

Electropalatographic assessment of tongue-palate contact patterns

EPG assessment procedure. The WinEPG system was used to record the tongue-palate contacts and corresponding acoustic signal of each individual's speech output. The EPG system has been previously described in McAuliffe, Ward, and Murdoch (2001). Prior to assessment with the artificial palate all participants were required to undergo a period of desensitisation to enable them to adjust to the presence of the artificial palate within the oral cavity. The majority of participants produced normal speech articulation (i.e., consistent with the no-palate condition) as judged by a speech pathologist following 45 minutes of desensitisation. However, some participants required much longer periods of desensitisation. Furthermore, even following extended periods of up to three hours wearing the artificial palate some participants in the control groups (particularly younger participants) continued to produce a slight perceptual distortion of the /s/ sound on some repetitions of the consonant in connected speech. This data remained in the final data set and will be discussed.

Three words embedded in the sentence "I saw a ___ today" (e.g., I saw a t̲ea today) were repeated ten times by each speaker in two vowel environments. This resulted in a total of 60 sentences per speaker. The word-initial consonants investigated included the lateral approximant /l/, alveolar fricative /s/ and the alveolar stop /t/. These consonants were produced in both the /i/ and /a/ vowel environments. Three individuals from the participant group with PD (participants one, four and six) were assessed using the Reading EPG3 system prior to the system upgrade to WinEPG. These participants were unavailable for re-assessment using WinEPG; however this did not affect, in any way, the data captured or the ability of results from the two systems to be compared. Furthermore, participant number four was unable to read the full EPG sentence list. Instead, this participant produced the sentence "I saw a ____" in the /i/ vowel environment only (a total of 30 sentences). Each sentence repetition was saved to an individual file for data analysis.

EPG data analysis. Each EPG and acoustic file was saved to CD-ROM and loaded into the data analysis program EPGLAB (Scott, & Goozee, 2002). From these files, a series of procedures and calculations were conducted on the data from each utterance of the participants. These included generating individual representative frames of contact and examining the spatial palatal features of articulatory contact.

Representative frames of contact. In the present investigation, the middle frame during the period of maximum contact was used to provide a picture of each participant's pattern of palatal contact for each consonant production. Two forms of representative frames of contact were generated in the present investigation: an individual representative frame (IRF) and an overall representative frame (ORF) (McAuliffe et al., 2001).

Spatial palatal measures. A series of spatial palatal measures were used to extract relevant information from the participants' frames of maximum contact and IRFs. These consisted of indices and measures used previously by a variety of authors. Specifically, these measures included: amount of tongue-palate contact, most anterior row contacted, number of rows with complete closure, length of closure in the midline, location of the point of maximum constriction, groove width and the modified Centre of Gravity Index (mCOG) (Hardcastle, Gibbon, & Jones, 1991; Hardcastle, Gibbon, & Nicolaidis, 1991; Jones, & Hardcastle, 1995; McAuliffe et al., 2001; Goozee, Murdoch, & Theodoros, 2003). The mCOG differs slightly from the commonly used Centre of Gravity (COG) index (Hardcastle et al., 1991; Jones, & Hardcastle, 1995) as progressively higher weighting is allocated to contact that occurs in the more posterior regions of the palate (Scott, & Goozee, 2002). Therefore, an mCOG index score of 2.00 using the EPGLAB program would indicate a concentration of contact in the anterior or alveolar region of the palate. In contrast, using the COG index (Hardcastle et al., 1991; Jones, & Hardcastle, 1995) a score of 2.00 would indicate contact concentrated in the posterior or velar regions of the palate.

Results

Statistical comparisons and post-hoc analysis between the three groups were undertaken using either parametric or non-parametric statistics dependant upon the data type and presence of homogeneity of variance. Therefore, either a one-way Analysis of Variance (ANOVA) or a Kruskal-Wallis one-way analysis of variance was undertaken for group comparisons with either t-tests or Mann-Whitney U tests for post-hoc comparisons. The p-value was set at .05. Consonant sounds were investigated individually in their respective vowel environments as it was thought that due to the paucity of group studies undertaken to date using EPG in speech pathology, information regarding tongue-palate contact patterns would be best described in specific vowel environments.

Perceptual assessment results

Speech sample analysis results. A Kruskal-Wallis one-way analysis of variance procedure revealed a significant difference between the three participant groups for the parameters of overall intelligibility (χ^2=13.22, p=.001) and precision of consonants (χ^2=20.57, p<.001). No significant differences were found between the three groups for length of phonemes (χ^2=2.95, p=.229) and precision of vowels (χ^2=1.78, p=.411). Post-hoc analysis revealed that the participant group with PD demonstrated significantly reduced overall intelligibility when compared to both the AC (U=12.00, p=.021) and YC (U=12.00, p=.021) participant groups. Similar levels of overall intelligibility (i.e., normal) were demonstrated by the AC and YC participant groups (U=32.00, p=1.00). On the parameter of precision of consonants, the participant group with PD demonstrated significantly impaired consonant imprecision when compared to both the AC (U=.00, p<.001) and YC (U=2.00, p<.001) groups. The AC and YC groups demonstrated similar levels of consonant precision (U=28.00, p=.721).

Perceptual analysis of electropalatographic consonant productions

Percentage of consonants accurately articulated. The mean scores and statistical comparisons for percentage of consonants accurately articulated by each of the three participant groups for the six consonant-vowel combinations are located in Table II. Statistical examination revealed significant differences (p<.01) between the three groups for their percentage of consonants accurately articulated during the production of /si/, /sa/, /ti/ and /ta/ (see Table II). Post-hoc testing revealed that for the production of /si/ the participant group with PD demonstrated significantly reduced percentage of consonants accurately articulated when compared to the AC (U=4.00, p=.002) and YC groups (U=13.50, p=.027). In addition, the YC group exhibited significantly reduced percentage of consonants accurately articulated when compared to the AC group (U=6.00, p=.009). In the production of /sa/, the participant group with PD demonstrated significantly reduced percentage of consonants accurately articulated when compared to both the AC (U=5.00, p=.003) and YC

Table II. Results of a Kruskal-Wallis one-way analysis of variance for perceptual evaluation of the percentage of consonants accurately produced by the participants with Parkinson's disease (PD) (n=9 in the /i/ vowel environment, n=8 in the /a/ vowel environment), aged control (AC) participants (n=7), and young control (YC) participants (n=8) during the electropalatographic assessment. Post-hoc analysis is also displayed with means exhibiting different corresponding letters in subscript (e.g., *a*, *b*) statistically significant at $p \leqslant .05$.

	PD Group		**AC Group**		**YC Group**			
Cons. Vow.	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	χ^2	**p**
/li/	95.59	9.78	100.00	.00	100.00	.00	3.48	.176
/la/	95.56	10.13	100.00	.00	100.00	.00	3.48	.176
/si/	56.67	28.28	97.50	4.63	83.75	15.06	13.21	.001***
	a		*b*		*c*			
/sa/	52.22	30.32	97.50	7.07	83.75	22.00	10.46	.005**
	a		*b*		*b*			
/ti/	72.54	22.30	95.00	14.14	98.75	3.54	10.24	.006**
	a		*b*		*b*			
/ta/	69.26	30.36	100.00	.00	100.00	.00	12.45	.002**
	a		*b*		*b*			

Note: **=$p \leqslant .001$, ***=$p \leqslant .01$. Cons. Vow=Consonant and vowel combination. SD=standard deviation.

groups (U=14.50, p=.036). In the production of /t/ in both the /i/ and /a/ vowel environments respectively, the participant group with PD demonstrated significantly reduced percentage of consonants accurately articulated when compared to both the AC (U=11.50, p=.031; U=10.50, p=.023) and YC groups (U=9.50, p=.008; U=12.00, p=.021).

Perceptual error types. The articulatory errors of the three participant groups were analysed according to error description and error type. Results revealed that all errors were perceived as distortions. For the lateral approximant /l/, a total of three errors only in each vowel environment were made by the participant group with PD. These errors were perceived as undershot by the perceptual judges. No perceptual errors were recorded for either control group. Examination of perceptual results for the alveolar fricative /s/ revealed approximately 40 perceptual errors in each vowel environment by the participant group with PD. These errors were made by eight and seven of the participants with PD respectively in the /i/ and /a/ vowel environments and were generally perceived as undershooting of the target consonant. While minimal articulatory errors were perceived in the AC group, the YC group demonstrated 13 errors in each vowel environment. These perceived errors were made by seven and four of the YC participants in the /i/ and /a/ vowel environments respectively. The majority of these productions were perceived by the perceptual judges to be overshot, approaching /θ/ in their production. For the alveolar stop /t/, the group with PD exhibited 23 and 27 errors in the /i/ and /a/ vowel environments. These errors were made by seven and eight participants respectively. In the /i/ vowel environment, the majority of these error productions were perceived as distortions only. However, in the /a/ vowel environment approximately half of all errors were perceived as undershooting of the target consonant. Minimal errors were perceived in the two control groups.

Electropalatographic assessment results

Following initial screening of the electropalatographic data set 25 files were removed from analysis as they were corrupted during data collection. A further four files were removed from analysis as the 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 PD group. As participant three was unavailable for reassessment 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 activated.

Representative frames of contact. Due to the substantial numbers of IRFs of contact from the participants in the present study, only ORFs are presented in the current paper. Figures 1 to 3 contain the ORFs generated for each subject group.

Spatial palatal measures

Amount of tongue-palate contact. Descriptive statistics for the number of tongue-palate contacts exhibited at the point of maximum contact for the three participant groups are presented in Table III. A one-way ANOVA revealed significant differences ($p<.05$) between the three groups for the number of contacts at the point of maximum contact

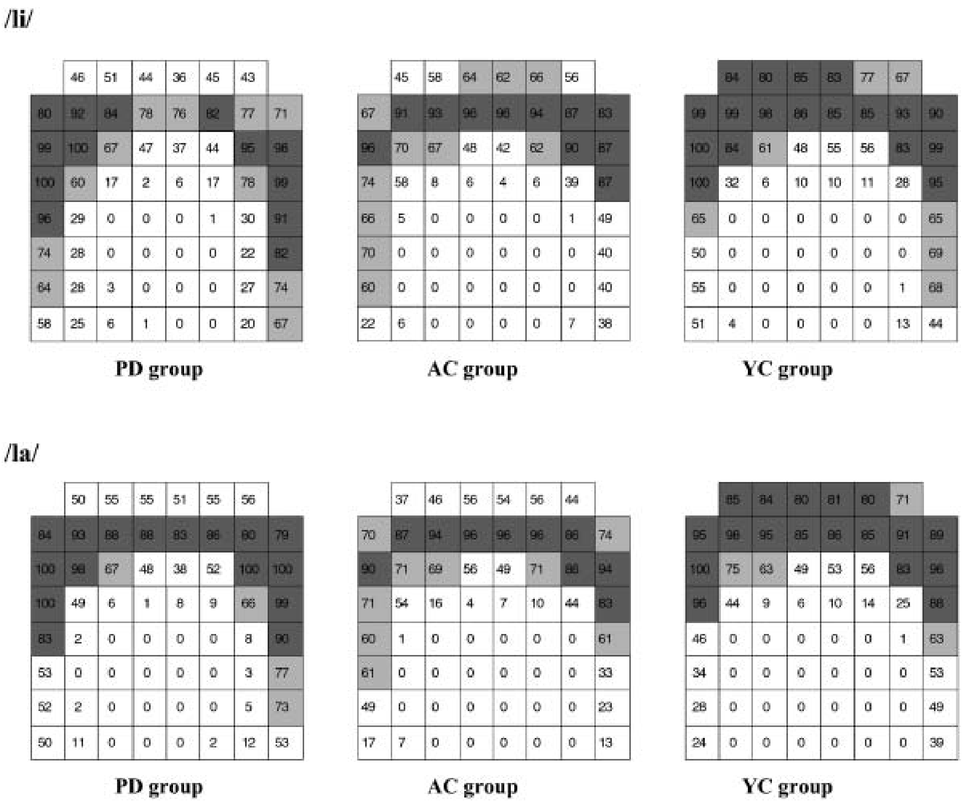

Figure 1. Overall representative frames of contact for the lateral approximant /l/ in the /i/ and /a/ vowel environments across the three participant groups. PD=Parkinson's disease, AC=aged control, YC=young control.

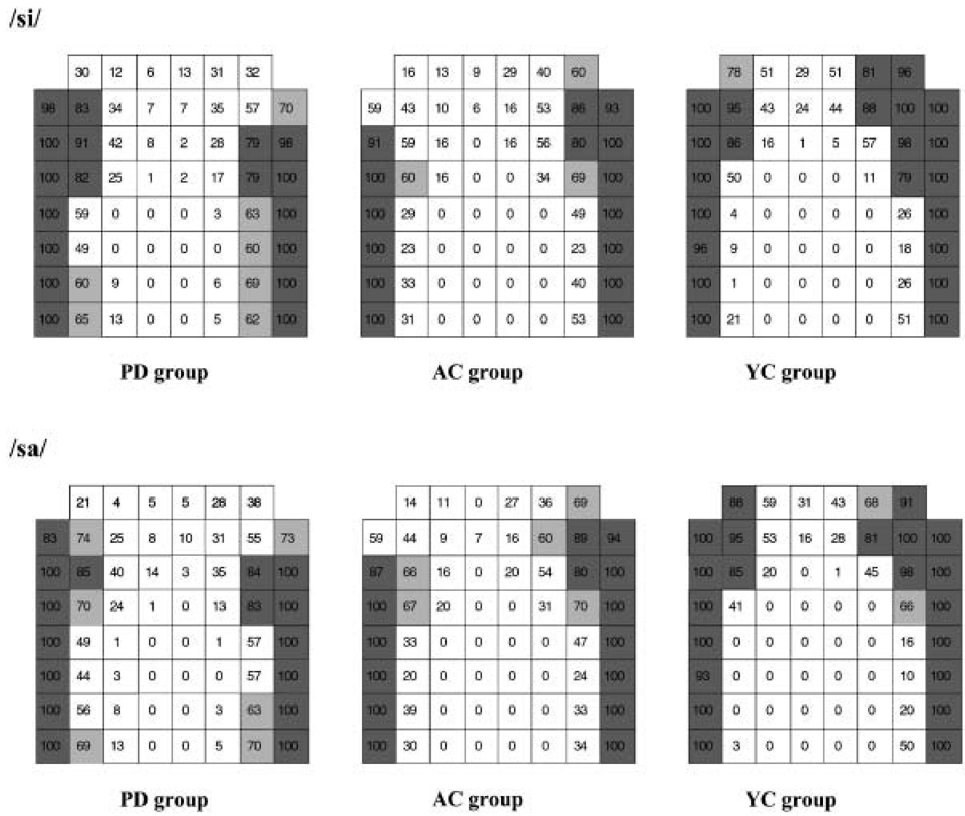

Figure 2. Overall representative frames of contact for the alveolar fricative /s/ in the /i/ and /a/ vowel environments across the three participant groups. PD=Parkinson's disease, AC=aged control, YC=young control.

during the production of the alveolar fricative /s/ in both the /i/ and /a/ vowel environments. No other significant differences were observed.

Post-hoc analysis using t-tests (see Table III) revealed that the participant group with PD demonstrated significantly less electrodes contacted at the point of maximum contact when compared to the YC group during the production of /si/ ($t=-2.77$, $p=.014$) and /sa/ ($t=-2.72$, $p=.016$). In addition, the AC group demonstrated significantly less electrodes contacted at the point of maximum contact to the YC group during the production of /si/ ($t=-3.25$, $p=.007$) and /sa/ ($t=2.67$, $p=.019$).

Patterns of tongue-palate contact. Table IV contains the mean and standard deviation results of the three participant groups on the mCOG index (Scott, & Goozee, 2002). Statistical analysis, using a one-way ANOVA, revealed significant differences ($p<.001$) between the three groups for their mCOG score during the production of the alveolar fricative /s/ in both the /i/ and /a/ vowel environments (see Table IV).

Post-hoc analysis using t-tests (see Table IV) revealed that the participant group with PD demonstrated significantly increased mCOG scores when compared to the YC group during the production of /si/ ($t=5.78$, $p<.001$) and /sa/ ($t=5.92$, $p<.001$). Furthermore, the AC group also demonstrated significantly increased mCOG scores to the YC group during the production of /si/ ($t=4.23$, $p=.001$) and /sa/ ($t=4.60$, $p<.001$).

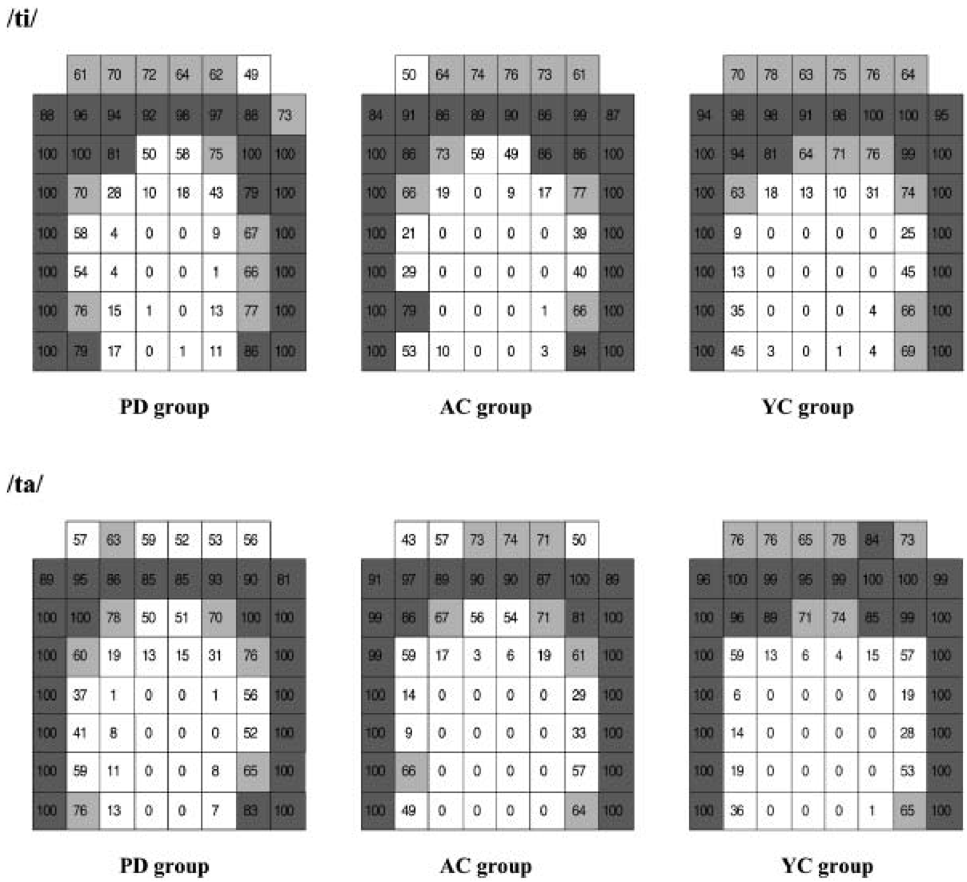

Figure 3. Overall representative frames of contact for the alveolar stop /t/ in the /i/ and /a/ vowel environments across the three participant groups. PD=Parkinson's disease, AC=aged control, YC=young control.

Table III. Mean values and statistical comparison of the number of contacts at the point of maximum contact for the participants with Parkinson's disease (PD) (n=9 in the /i/ vowel environment and n=8 in the /a/ vowel environment), aged control (AC) participants (n=7) and the young control (YC) participants (n=8). The results of post-hoc comparisons are also included in the present table. Means exhibiting different corresponding letters in subscript (e.g., *a*, *b*) are statistically significant at p ⩽ .05.

	PD Group		AC Group		YC Group			
Cons. Vow	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**F**	**p**
/li/	19.42	2.82	18.99	3.53	20.87	2.29	.90	.423
/la/	19.42	3.40	18.67	2.85	20.70	2.98	.72	.501
/si/	13.66 *a*	3.50	13.26 *a*	2.88	17.83 *b*	2.56	5.48	.012*
/sa/	13.08 *a*	3.43	13.46 *a*	2.77	17.46 *b*	3.01	4.86	.019*
/ti/	22.16	2.21	21.34	3.61	22.90	1.92	.67	.525
/ta/	21.05	2.44	20.79	3.18	23.06	1.89	1.89	.177

Note: *=p ⩽ .05. Cons. Vow=consonant and vowel combination. SD=standard deviation.

Table IV. Modified Centre of Gravity (mCOG) index results and statistical comparison across the participants with Parkinson's disease (PD) (n=9 in the /i/ vowel environment, n=8 in the /a/ vowel environment), aged control (AC) group (n=7), and young control (YC) participants. The results of post-hoc comparisons are also included in the present table. Means exhibiting different corresponding letters in subscript (e.g., *a*, *b*) are statistically significant at p ⩽ .05.

	PD Group		**AC Group**		**YC Group**			
Cons. Vow.	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**F**	**p**
/li/	3.45	.56	3.04	.72	3.06	.44	1.39	.272
/la/	3.41	.47	2.92	.74	2.84	.39	2.57	.102
/si/	4.67 *a*	.31	4.45 *a*	.27	3.87 *b*	.26	17.87	<.001***
/sa/	4.73 *a*	.36	4.40 *a*	.25	3.83 *b*	.23	19.71	<.001***
/ti/	4.11	.28	4.00	.31	3.82	.26	2.25	.130
/ta/	4.09	.34	3.91	.32	3.71	.21	3.37	.055

Note: *=p ⩽ 0.05, ***=p ⩽ .001. Cons. Vow.=consonant and vowel combination. SD=standard deviation.

Additionally, each individual's IRF of contact was further examined and most anterior row contacted (for /l/ and /t/), number of rows with complete closure (for /l/ and /t/), number of rows with the medial electrodes contacted (for /l/ and /t/) and location of the point of maximum constriction and groove width (for /s/) were detected. The results of this examination are located in Table V. A Kruskal-Wallis one-way analysis of variance revealed significant differences between the three groups for location of the point of maximum constriction and groove width during the production of the alveolar fricative /s/ in both vowel environments (p<.05) (see Table V). All other comparisons were non-significant.

Post-hoc analysis was conducted using Mann-Whitney U tests. Results revealed that the participant group with PD demonstrated a significantly more posterior point of maximum constriction to the YC group in both the /i/ (U=5.50, p=.003) and /a/ (U=6.00, p=.009) vowel environments. Post-hoc analysis of groove width revealed that the participant group with PD demonstrated significantly increased groove widths in both the /i/ (U=9.00, p=.008) and /a/ (U=11.00, p=.028) vowel environments when compared to the YC group (see Table V).

Discussion

The results of the present investigation revealed perceived consonant imprecision in the group of individuals with PD. Perceptual analysis of the accuracy of consonant production during the EPG assessment revealed that the participant group with PD demonstrated significantly more articulatory errors than both the aged and young control groups during the production of the alveolar fricative /s/ and the alveolar stop /t/ in both the /i/ and /a/ vowel environments. Analysis of articulatory error types indicated that the presence of perceived undershooting of articulatory targets distinguished the participant group with PD from the control groups.

Despite this, instrumental examination of tongue-palate contact patterns did not reveal the presence of undershooting of lingual contact in the group with PD. Indeed, the tongue-palate contact patterns of the participant group with PD were generally similar to those of the control groups. Only the potential influence of ageing on lingual palatal contact patterns for the alveolar fricative /s/ was highlighted in the results of the current study. Both the participant group with PD and the aged control group demonstrated similar tongue-palate contact patterns during the production of /s/ that were different to those of

Table V. Comparison of group results on the spatial parameters of tongue-palate contact across the participants with Parkinson's disease (PD) (n=9 in the /i/ vowel environment and n=8 in the /a/ vowel environment), aged control (AC) group (n=7), and young control (YC) group (n=8). The results of post-hoc comparisons are also included in the present table. Means exhibiting different corresponding letters in subscript (e.g., *a*, *b*) are statistically significant at $p \leqslant .01$.

	PD Group		AC Group		YC Group			
Parameter	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	χ^2	**p**
Most anterior row contacted								
/li/	1.11	.33	1.29	.49	1.13	.35	.97	.615
/la/	1.38	.52	1.14	.69	1.00	.00	2.53	.282
/ti/	1.33	.50	1.29	.49	1.13	.35	1.00	.605
/ta/	1.25	.46	1.14	.38	1.13	.35	.48	.786
No. rows with complete closure								
/li/	1.00	.87	1.00	.82	1.63	.92	2.51	.285
/la/	1.25	.89	1.29	.76	1.88	.99	2.54	.281
/ti/	1.22	.67	1.57	.79	2.00	.53	5.23	.073
/ta/	1.38	.92	1.57	.53	2.13	.64	4.22	.121
No. rows with medial electrodes contacted								
/li/	1.33	.71	1.86	.69	1.63	.92	1.77	.412
/la/	1.50	.76	1.71	.49	2.13	.64	3.28	.195
/ti/	1.89	.60	1.86	.90	2.00	.53	.26	.878
/ta/	1.75	1.04	1.71	.49	2.25	.71	2.29	.319
Location point of max. constriction (row no.)								
/si/	2.75 *a*	.76	2.29 *a, b*	1.04	1.50 *b*	.53	7.56	.023*
/sa/	2.64 *a*	.69	2.36 *a, b*	.85	1.56 *b*	.50	7.37	.025*
Groove width (in no. of electrodes)								
/si/	3.33 *a*	1.00	2.71 *a, b*	.76	1.75 *b*	.89	8.94	.011*
/sa/	3.38 *a*	1.06	2.57 *a, b*	.79	2.00 *b*	1.07	6.41	.041*

Note: $* = p \leqslant .05$. No.=number, max.=maximum, SD=standard deviation.

the young control participants. Quantitatively, both groups demonstrated reduced numbers of electrodes contacted at the point of maximum contact in conjunction with increased mCOG values when compared to the young control group. Such results indicated that age-related reductions in lingual motor control may have resulted in reduced palatal contact and increased groove widths during /s/ production. The results of the current study will be discussed in greater detail in three consonant-specific sections.

Lateral approximant /l/

The participant group with PD demonstrated a high level of perceived articulatory accuracy in their production of the lateral approximant /l/. Only three errors in production were noted; all of which were distortions of the target consonant perceived as undershot by the judges (i.e., occurring from reduced tongue contact with the hard palate). Therefore, as anticipated, examination of the ORFs of contact revealed similar tongue-palate contact patterns across the three groups. Furthermore, these tongue-palate contact patterns were consistent with previous descriptions of EPG patterns in normal speakers (Hardcastle, & Barry, 1985; Hardcastle, Morgan Barry, & Clark, 1987; Hardcastle et al., 1991; Dagenais, Lorendo, & McCutcheon, 1994; Hardcastle, & Gibbon, 1997; Murdoch, Gardiner, & Theodoros, 2000; McAuliffe et al., 2001).

However, closer analysis of the ORF for /li/ by the participant group with PD revealed inconsistent closure patterns at row two on the palate. Indeed, the two central electrodes on this row were contact on only 78 and 76% of repetitions by the participant group. Such findings indicated that either a speaker or speakers demonstrated incomplete closure on the central palate during the production of /l/ in the /i/ vowel environment. Further examination of the IRFs of contact of the participants with PD confirmed this finding with two participants (eight and two) lacking lingual palatal contact on the central electrodes at row two across all repetitions of the consonant. In the case of participant eight, it appeared that this speaker's lingual contact simply occurred more posteriorly to that of other participants with closure always occurring at row three (the post-alveolar zone) and extending into the central electrodes of row two (the alveolar zone) on 60% of repetitions. However, the results from repetitions of the target consonant by participant two indicated that he did not achieve consistent closure of the medial electrodes in the alveolar zone. Indeed, the participant's IRF was consistent with a pattern of articulatory undershoot, resembling a fricative across approximately half of all repetitions. Interestingly, this pattern of articulatory undershoot contrasted with the transcriptions of the perceptual judges who noted that participant two's production of /li/ was accurate in all but one repetition of the target consonant. Such a result served to highlight the importance of objective measures of articulatory performance in combination with perceptual investigations.

The remaining quantitative analysis supported the perceptual findings of minimal impairment to /l/ production in the current group of participants with PD. The participant group with PD demonstrated similar levels of tongue-palate contact and mCOG values to the control groups in addition to similar scores for most anterior row contacted, number of rows with complete closure and number of rows with the medial electrodes activated. On the basis of these findings, it appeared that the current group of speakers with PD and mild-to-moderate dysarthria demonstrated similar perceptual realisations and tongue-palate contact patterns for the lateral approximant /l/ in both vowel environments to both the aged and young control speakers.

Alveolar fricative /s/

Perceptual examination of /s/ productions during the EPG assessment revealed that the participant group with PD demonstrated significantly more articulatory errors than both control groups in both the /i/ and /a/ vowel environments. The majority of these articulatory errors were perceived as undershot by the perceptual judges. This result compared favourably with the results of Logemann and Fisher (1981) who stated that the fricative productions of individuals with PD were reduced in their "sharpness" of articulation.

Errors in production were also noted in the control groups, particularly the young control group; however, these perceptual errors were quite different to those of the group with PD.

Specifically, the young control group demonstrated a high number of articulatory errors, most of which were perceived as overshot (approaching /θ/) by the perceptual judges. It is, therefore, likely that inadequate adaptation to the presence of the EPG palate in the oral cavity resulted in the error productions of the young control group. This was consistent with a previous study which found that participants who wore a dental prosthesis tended to overshoot the target gesture during the production of /s/ when initially speaking with the prosthesis in-situ (Hamlet, & Stone, 1978).

Although perceptual assessment revealed impaired consonant production in the participant group with PD (consistent with articulatory undershoot), examination of the group's ORFs revealed similar patterns of tongue-palate contact to the aged control group in both vowel environments. The ORFs of both of these groups were quite different to those of the young control group; demonstrating less contact in the anterior region of the palate and wider fricative grooves. Indeed, only the ORFs of the young control group were consistent with previous reports of tongue-palate contact patterns for the alveolar fricative (data that was acquired on young or middle aged adults) (Gibbon, & Hardcastle, 1987; Hardcastle et al., 1987; Hardcastle et al., 1991; Dagenais et al., 1994; Murdoch et al., 2000; McAuliffe et al., 2001; Goozee et al., 2003).

The view that the ORFs of the participant group with PD and the aged control groups demonstrated less contact in the anterior region of the palate to the young controls was substantiated statistically. Both the participant group with PD and the aged control group demonstrated significantly reduced numbers of electrodes contacted in the anterior section of the palate during alveolar fricative production when compared to the young control group. In addition, mCOG values demonstrated that the participant group with PD and the aged control groups productions of /s/ were centred further posteriorly on the palate to the young control groups. These results occurring in combination indicated that age effects were likely impacting upon lingual palatal contact patterns of both the group with PD and the aged controls, resulting in reduced contact by the tongue with the hard palate in the anterior section of the palate. It is also possible that high-frequency hearing loss associated with ageing contributed to a shift in palatal contact patterns, with speakers less able to self-monitor and hence, accurately produce their consonant productions.

Quantitative evaluation of groove width and location of maximum constriction also served to confirm, to an extent, the subjective interpretation of the ORFs. The present study found that the participants with PD and the aged control group demonstrated similar locations of the point of maximum constriction and groove widths. However, while the comparison of results between the participant group with PD and the young control group produced significant results, the comparison between the aged and young control groups did not. The finding of increased groove width in the participants with PD (when compared to the young control speakers) may relate to the undershooting recognised perceptually in the speech output of the participants with PD. Such a finding would support Logemann and Fisher's (1981) theory that the distortion of the target consonant noted in individuals with PD may have resulted from "an apparent decrease in the degree of constriction of the aperture through which the breath stream passed" (pp. 350–351) and provides some support for the theory that the speech disorder resulted, in part, from lingual undershoot. However, the pattern of results was interesting. It appeared that a trend towards increased groove width and more posterior location of the point of maximum constriction existed in the comparison between the aged and young controls that was further extended in the comparison between the aged controls and group with PD. Therefore, it is possible that with increased participant numbers a significant difference between the aged and young controls and also the aged controls and group with PD would eventuate. Such results may likely reflect the combination of both ageing and pathological effects of PD influencing the pattern of tongue-palate contact in individuals with PD.

Also of interest to the current study is the impact of the artificial palate upon speech production. Hamlet and Stone (1978) reported that the most striking feature of normal adult /s/ articulation following initial insertion of thick (4mm) palate was a reduction in groove width on palatographic examination. Furthermore, McFarland, Baum, and Chabot (1996) reported on the fricative production of 15 normal young adult speakers both with and without an artificial palate in-situ. The authors noted that ''production of the fricative /s/ appears to be highly susceptible to the perturbing effects of the artificial palate'' (McFarland et al., 1996, p. 1100). It was hypothesised that the complex lingual movement required for /s/ articulation may result in its susceptibility to effects from artificial palates (McFarland et al., 1996). Hence, it is possible that the artificial palate itself may have contributed to the reduced groove width demonstrated by the young control group. However, this suggestion must be balanced by the fact that all participants wore a similar EPG palate and the differences between the aged (PD and aged control groups) and young groups were salient. These findings do, however, highlight the need for further research into the impact of the EPG artificial palate on speech production. In particular, future research should undertake identical perceptual and acoustic investigations of articulation both with and without the EPG palate in-situ.

Alveolar stop /t/

Perceptual analysis indicated that the participant group with PD demonstrated significantly more articulatory errors in the production of the alveolar stop /t/ than either control group. In the /i/ vowel environment, the majority of the error productions were minor, characterised only as distortions of the target consonant. However, in the /a/ vowel environment approximately half of all error productions were identified as perceived undershooting of the target consonant.

Given the number of error productions demonstrated by the participant group with PD, it was surprising that all three participant groups, on their ORFs, demonstrated similar patterns of contact. These patterns were similar to those generated by previous studies into tongue-palate contact patterns in normal speakers (Hardcastle, Gibbon, & Jones, 1991; Dagenais et al., 1994; Hardcastle, & Gibbon, 1997; Gibbon, & Nicolaidis, 1999; Murdoch et al., 2000; McAuliffe et al., 2001; Goozee et al., 2003). A minor difference between the current group patterns was the presence of increased contact on the lateral columns of the ORF of both the participants with PD and the aged control groups. It appeared that the midsection of the tongue was raised in these groups during the production of /t/. This did not occur as often in the young control group and may be a compensatory process enacted by aged individuals as a form of lingual stabilisation (or bracing) during tongue tip movement.

The similar tongue-palate contact patterns of the three groups were further highlighted by an absence of significant results for number of tongue-palate contacts at the point of maximum contact, the mCOG index and scores for most anterior row contacted, number of rows with complete closure and number of rows with the medial electrodes activated. As a result, it appeared that articulatory undershoot was not responsible for the articulatory errors demonstrated by the participant group with PD during /t/ production. It is possible, however, that a reduction in the force of tongue contact with the hard palate was present in the group with PD. This occurrence could result in the perception of articulatory undershoot. Furthermore, deficits at a sub-lingual level or impairments to articulatory timing may also have resulted in the perceived distortion of the alveolar stop.

Conclusions and directions for further research

The results of the present study found that while perceived undershooting of consonant production generally distinguished the participant group with PD from the control groups, a pattern of reduced tongue-palate contact on EPG examination did not occur concurrent with the perceived error. Therefore, the theory that reductions in the amplitude of lingual movement or articulatory undershoot resulted in the impaired consonant production was not substantiated for the present group of participants with PD. These results were not anticipated as it was hypothesised that the perceived articulatory undershoot observed in the consonant productions of the group with PD would be quantified by reduced tongue-palate contact on the EPG assessment.

It is possible that the relatively mild nature of the speech deficits in the participant group with PD contributed to the failure to show that lingual undershoot contributed to the articulatory disorder. All individuals in the group with PD were perceived as having mild or moderately impaired articulation only. Previous investigations have noted that individuals who manifest a dysarthria, particularly a mild dysarthria, often exhibited relatively similar tongue-palate contact patterns to normal speakers (Murdoch et al., 2000; Goozee et al., 2003). Indeed, those investigations that demonstrated distorted tongue-palate contact patterns reported on the results of individuals with a moderate or severe dysarthric disturbance (Hardcastle, Morgan Barry, & Clark, 1985; Morgan Barry, 1995a, b; Goozee et al., 2003). It is possible that spatial distortions occur with increased severity of articulatory deficit and that in the case of individuals with a neurodegenerative disorder, and hence a potentially progressive articulatory disturbance, spatial distortions will occur only when a moderate-to-severe articulatory deficit is present. Therefore, future research should aim to investigate if the articulatory contact patterns of individuals with PD and a severe dysarthria manifest undershooting of tongue-palate contact.

It may also be that the current findings reflect a reduction in the force of tongue contact with the hard palate in the group with PD. If the force of tongue contact with the hard palate was reduced, it is possible that the judges perceived articulatory undershoot in the presence of normal tongue-palate contact patterns. Investigation of speech production using a pressure-sensing palate would provide further insight into this hypothesis.

It is further possible that the articulatory imprecision observed in the present group of participants with PD may have resulted from sub-lingual impairments or subtle deviations from normal articulatory timing rather than impaired tongue-palate contact patterns. Murdoch et al. (2000) reported EPG case-study data of an individual with multiple sclerosis who exhibited similar patterns of tongue-palate contact to control speakers in the presence of impaired articulatory timing. In addition, another case study examination of an individual with a mixed spastic-ataxic dysarthria using EPG noted better performance on the spatial aspects of articulatory production than the temporal aspects of articulation (Gibbon et al., 2000). Therefore, the articulatory errors of the present group of individuals with PD may be related to impairment in the temporal aspects of speech production, specifically impaired durations of the approach, release or closure durations of consonant production. Impairments in the duration of any of these phases of articulation may result in the perception of consonant imprecision. As a result a second component of this study, an examination of articulatory timing at sentence, word and segment level in the three participant groups, was conducted and is presented in the current edition of this journal.

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