Strength, Endurance, and Stability of the Tongue and Hand in Parkinson Disease

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Weakness and fatigue in the orofacial system often are presumed to contribute to the dysarthria associated with neuromotor disorders, although previous research findings are equivocal. In this study, tongue strength, endurance, and stability during a sustained submaximal effort were assessed in 16 persons with mild to severe Parkinson disease (PD) and a perceptible speech disorder. The same measures were taken from one hand for comparison. Only tongue endurance was found to be significantly lower in these participants than in neurologically normal control participants matched for sex, age, weight, and height. Analyses of data from a larger sample comprising the present and retrospective data revealed lower-than-normal tongue strength and endurance in participants with PD. No significant correlations were found between tongue strength and endurance, interpause speech rate, articulatory precision, and overall speech defectiveness for the present and previously studied participants with PD, bringing into question the influence of modest degrees of tongue weakness and fatigue on perceptible speech deficits.

KEY WORDS: Parkinson disease, dysarthria, tongue, strength, endurance

Muscle weakness is rarely detected during neurologic examination of persons with Parkinson disease (PD) (Yanagawa, Shindo, & Yanagisawa, 1990). However, evidence is mounting for weakness in the limbs (Brown, Corcos, & Rothwell, 1997; Corcos, Chen, Quinn, McAuley, & Rothwell, 1996; Koller & Kase, 1986; Stelmach, Teasdale, Phillips, & Worringham, 1989; Yanagawa et al., 1990) and respiratory system (Tzelepis, McCool, Friedman, & Hoppin, 1988). Weakness in the lips (Netsell, Daniel, & Celesia, 1975; Wood, Hughes, Hayes, & Wolfe, 1992) and tongue (Dworkin & Aronson, 1986; Solomon, Lorell, Robin, Rodnitzky, & Luschei, 1995) also has been reported for this population. In contrast, fatigue often is recognized as a clinical sign in PD (Friedman & Friedman, 1993; Lees, 1981; Mayeux et al., 1986; McDowell, 1971; Schwab, England, & Peterson, 1959; Wilson, 1925), but has not been demonstrated in the orofacial system (Solomon et al., 1995). Another key factor that may reflect motor control problems is motor instability (e.g., Kelso, 1995; Newell & Corcos, 1993). Instability during submaximal sustained force procedures has been documented in the forefinger (Gentil, Perrin, Tournier, & Pollack, 1999; Kunesch, Schnitzler, Tyercha, Knecht, & Stelmach, 1995) and lips and tongue (Gentil et al., 1999) of persons who have PD.

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In a previous study, Solomon et al. (1995) found evidence for weakness (reduced strength) but not fatigue (inferred from reduced endurance) in the tongue and hand in 19 persons with mild to moderate PD. Although stability of the tongue and hand during the endurance task (involving sustained submaximal muscle contraction) was not examined directly, a potential relation between endurance and stability was discussed (Solomon et al., 1995). That is, if a muscle is unable to sustain an output level because of instability, the trial could be terminated prematurely and the result would be misinterpreted as fatigue. The previous results did not support such an association, because endurance did not differ between participant groups. However, it was speculated that motor instability might be disproportionately evident in people with more severe tongue impairments and that the pattern of instability over the duration of endurance trials might be illuminating.

A potential relation between speech disorders and nonspeech tongue function measures (i.e., strength and endurance) can be inferred from studies that have examined disordered speakers with a variety of etiologies. Specifically, reduced tongue strength has been reported for persons with speech disorders resulting from amyotrophic lateral sclerosis (ALS; DePaul & Brooks, 1993; Dworkin, Aronson, & Mulder, 1980; Langmore & Lehman, 1994), stroke (Thompson, Murdoch, & Stokes, 1995), traumatic brain injury (TBI; Stierwalt, Robin, Solomon, Weiss, & Max, 1995), and developmental apraxia of speech (DAS; perhaps suggesting a concomitant dysarthria in a subset of cases; Murdoch, Attard, Ozanne, & Stokes, 1995; Robin, Somodi, & Luschei, 1991), among other disorders (Dworkin, 1980; Dworkin & Aronson, 1986; Palmer & Osborn, 1940; Sanders, 1968; Sanders & Perlstein, 1965). Likewise, reduced tongue endurance has been reported for children with dysarthria who had sustained a TBI (Stierwalt et al., 1995) and children with DAS (Murdoch et al., 1995; Robin et al., 1991).

Studies that have attempted to correlate tongue strength or endurance with severity of dysarthria (using equal-appearing-interval scales, EAI) have produced conflicting results, depending on the population being studied. Significant correlations between tongue function and severity of dysarthria have been reported for adults with ALS (DePaul & Brooks, 1993; Dworkin et al., 1980; Langmore & Lehman, 1994) and for children post-TBI (Stierwalt et al., 1995). Studies that failed to find a significant correlation examined adults who had sustained a stroke (Thompson et al., 1995) and those with a variety of speech disorders (Dworkin & Aronson, 1980). More specific speech measures, such as intelligibility and speech alternating-motion rates (AMRs), were less likely to correlate with nonspeech tongue function measures (DePaul & Brooks, 1993; Dworkin & Aronson, 1986; Dworkin et al., 1980; McHenry, Minton, Wilson, & Post, 1994). The study by Solomon et al. (1995) was the first to systematically document reduced tongue strength in a group of persons with Parkinson disease. Despite minimal impairment of speech in most of their participants, they found weak but statistically significant negative correlations between tongue strength and both articulatory imprecision and overall speech defectiveness for a picture-description task.

A final issue of interest is the potential relation between tongue strength and speech rate. Because the rate of muscle contraction slows with reduced strength of normal muscle (Hill, 1938) as well as in persons with PD (Corcos et al., 1996; Wierzbicka, Weigner, Logigian, & Young, 1991), speech rate may be determined in part by muscle strength (Luschei, 1991). Although no such relationship emerged previously, it was speculated that these variables might correlate for persons with PD who have more severe speech-rate disturbances (Solomon et al., 1995).

The present study was conducted to examine strength and endurance of the tongue and hand in persons with PD who have a wider range of severity of disease and dysarthria than those studied previously (Solomon et al., 1995). A second objective was to examine, based on the data generated during the endurance task, differences between persons with PD and those who are neurologically normal for tongue and hand stability as well as changes in stability as the structure was fatigued. A third objective of this research was to investigate whether abnormalities of tongue strength and endurance were related to perceptual characteristics of speech and speech rate in persons with PD.

Method

Participants

Participants were 16 adults with idiopathic PD and 16 neurologically normal adults. Each group included 12 men and 4 women; ages ranged from 54 to 84 years. Control participants were matched 1:1 as closely as practicable to participants with PD for sex, age, weight, and height (see Table 1).

Participants, all native speakers of English, reported negative histories for neurologic, speech, voice, and language disorders other than those associated with PD. They reported no exceptional use of the tongue or hand (e.g., trumpet or piano playing, debating) for at least the past 5 years, except that two (Control C & PD F) engaged in hand exercises for strength and dexterity. During initial telephone interviews, candidates with PD described the severity of their motor signs and their speech. Inclusion originally depended on descriptions

Table 1. Demographic information for all participants and severity of PD for participants with Parkinson disease.

	Parkinson disease								Control			
Participant	Sex	H&Y[a]	UPDRS 3[b] (motor)	UPDRS (total)	Duration (yr)	Age (yr)	Weight (kg)	Height (cm)	Age (yr)	Weight (kg)	Height (cm)	UPDRS 3[b] (motor)
A	F	2.5	10.8	32.3	13	56	56	160	55	52	165	1.0
B	M	2.0	20.3	39.8	3	59	77	188	60	81	183	2.5
C	M	2.0	16.9	30.9	4	59	88	178	60	93	180	1.0
D	M	2.0	19.3	40.3	3	64	77	178	64	77	180	3.0
E	M	3.0	14.3	35.8	13	69	77	168	72	85	178	2.9
F	M	2.0	15.4	34.4	7	71	61	170	71	83	178	0.0
G	M	2.0	17.0	32.0	7	68	77	178	70	79	178	4.5
H	F	2.0	14.2	27.7	2	70	76	160	73	73	163	4.9
I	M	3.0	21.7	37.7	7	67	88	183	67	83	178	0.0
J	M	3.0	21.7	41.2	10	65	105	193	66	117	198	1.2
K	F	3.0	20.1	35.4	5	79	73	163	78	68	163	1.3
L	M	3.0	19.4	52.9	23	63	67	178	61	74	180	1.3
M	M	3.5	25.1	59.1	7	79	63	170	85	75	170	0.1
N	M	3.5	25.2	56.7	4	81	66	175	81	68	180	6.0
O	M	4.0	30.4	62.9	23	77	59	175	76	67	170	5.4
P	F	4.0	28.6	67.6	32	68	56	163	71	60	160	2.5

[a]H&Y = Hoehn & Yahr stage. [b]UPDRS 3 = Part 3 (motor examination) of the Unified Parkinson Disease Rating Scale.

of motor signs that were consistent with at least Stage 3 on the Hoehn and Yahr (1967) scale (i.e., both sides of the body and balance were affected). Inclusion also required a reported change in speech and/or voice since acquiring PD. These selection criteria were established to allow investigation of relations between disease severity, hand and tongue function, and dysarthria. Dysarthria was included as a criterion because severity of the disease and dysarthria do not always correspond (Hoehn & Yahr, 1967; Metter & Hanson, 1986). In six cases, the motor severity criterion was relaxed as long as dysarthria was present, because it was difficult to locate an adequate pool of candidates who could pass the dementia screening.

Instrumentation

Tongue and hand functions were assessed with the Iowa Oral Performance Instrument (IOPI). The IOPI contains a pressure transducer that senses pressure exerted on an air-filled bulb. Second-generation tongue bulbs (soft vinyl blue plastic bulbs attached to a polyethylene tube, 2 mm inside diameter) were used. Because of slightly different internal volumes and surface areas, pressure values obtained from the first-generation (clear) tongue bulbs must be multiplied by 0.87 to be comparable to the present data. The hand bulb is a 1 mL pipette bulb inserted into a 10 mL rubber syringe bulb and surrounded by water sealed within the outer bulb (Robin, Goel, Somodi, & Luschei, 1992; Robin, Somodi, & Luschei, 1991).

The pressure exerted on the air-filled bulbs was detected and displayed digitally or by LED on the IOPI. Additionally, the pressure data were amplified (18.4 mV/kPa) and digitized via custom-designed hardware and imported through the serial port of a laptop computer. The signal was input to a microprocessor with a built-in A:D 8-bit converter at a sampling rate of 88 Hz.

Speech samples were recorded with a high-quality cassette tape recorder (Marantz PMD 420) and electret microphone (Realistic tie-pin) clipped to the participant's shirt. The recording level was adjusted for each participant to ensure a strong signal while avoiding distortion by clipping. Listeners later heard the tapes over headphones (Yamaha YH-2).

Procedures

Participants with PD were evaluated in their homes or, in three cases, a homelike environment to alleviate anxiety and to include participants with the most severe PD possible. Control participants were seen in a comfortable university clinic room or office (nonlaboratory setting) and, in one case, the participant's home. All provided written informed consent.

Dementia was screened with the Iowa Screening Battery for Mental Decline (Eslinger, Damasio, & Benton, 1984; Eslinger, Damasio, Benton, & Van Allen, 1985). Only participants classified as "highly probably normal" were included. For more detailed assessment of PD, the Unified Parkinson Disease Rating Scale

(UPDRS; Fahn, Elton, & Members of the UPDRS Development Committee, 1987) was administered in its entirety to the participants with PD by the first author, who was trained to be a reliable examiner by an experienced neurologist. The Motor Examination section of the UPDRS was administered immediately before (11 cases), during (4 cases), or immediately after (1 case) collection of the tongue and hand pressure data, depending on the timing of data collection to medication cycle. The UPDRS Motor Examination was administered to the control participants to confirm normal motor status (Table 1). Dental occlusion was assessed, and gross abnormalities that might affect testing were ruled out. Finally, participants were weighed on a portable digital scale.

For the PD participants who received levodopa therapy (all except C and H), data collection began 30 min after levodopa was ingested; leeway was allowed for participants on controlled-release levodopa. Testing was completed in approximately 1 hr. The order of testing the tongue and hand was alternated between participants. Tongue strength was assessed by asking the participant to "squeeze as hard as you can" with the anterior dorsum of the tongue against the IOPI tongue bulb placed against the hard palate. To assess hand strength, the IOPI hand bulb was placed in the palm of the preferred hand (except for PD participants L, N, & P because of prior injuries of the dominant hand or wrist), and participants squeezed the bulb as hard as possible. The best performance of three trials was taken as the maximum strength, unless a greater pressure was generated during a subsequent task. At this juncture, participants performed a variety of other tasks with the IOPI as part of a larger investigation.

Next, speech samples were recorded for approximately 10 min. The speech tasks of interest for the present article were picture description and extemporaneous monologue. The IOPI tasks performed so far were not fatiguing and were presumed not to influence speech. The speech tasks were performed before the effortful and fatiguing tongue endurance task because of its potential influence on speech.

Tongue and hand endurance were assessed once each by the participant maintaining 50% of maximal pressure (P_{max}) as long as possible. Visual feedback was provided via the IOPI's LED display; the middle LED was set to represent 50–60% of P_{max}. The experimenter (NPS) provided spirited verbal encouragement throughout the trial. Trials were terminated when the pressure dropped precipitously or when 40% of P_{max} could not be maintained for a few seconds. Although trials were timed with a stopwatch, specific criteria for determining endurance from the digitized pressure records were developed and are described in Data Analysis.

Data Analysis

The pressure data digitized into files on the laptop computer were transferred to a desktop computer (IBM PS/2, Model 70, 386), converted to CODAS format (software by DATAQ, Akron, OH), and calibrated for pressure (in kPa).

Strength was noted online during the experiment from the IOPI's digital display and later confirmed to be accurate from the digitized pressure files. Endurance was analyzed from the digitized pressure files. Measurement began when the pressure reached 50% of P_{max} and ended when one of three criteria was met: (a) at the beginning of a precipitous drop in the pressure signal, (b) after the pressure signal was >40% and <50% of P_{max} for 2 s, or (c) after the pressure signal was <40% of P_{max} for 0.5 s. The development of these rules was based on previous experience terminating endurance trials with a stopwatch, and the rules allowed for some fluctuation in the pressure signal. Twelve (19%) of the endurance trials (6 PD, 6 control; 3 tongue, 3 hand trials for each participant group) were later remeasured. Intrarater and interrater agreement were within 0.1 s for 92% and 83% of the trials, respectively.

Stability also was determined from the endurance trials. Because changes in stability over time during a fatiguing task were of interest, stability (as indicated by the coefficient of variation) was determined with a custom computer program for five 3-s segments of each trial. Selection of the specific procedures evolved after attempting curve fitting, examining from 2 to 5 segments of data ranging in duration from 0.5 to 10 s, and considering several descriptive statistics. The method selected seemed to best quantify the overall stability and changes in stability over time. The rationale for using a fixed segment duration was to standardize the number of data points in the calculation of standard deviation, which is affected by sample size. Most endurance trials lasted 15 s or longer; for these, five 3-s segments were analyzed, each with its midpoint at 10, 30, 50, 70, and 90% of the trial. For trials that lasted 9–15 s, three 3-s segments, with midpoints at 17, 50, and 83% of the trial, were analyzed. For trials lasting 6–9 s, two 3-s segments with midpoints at 25 and 75% of the trial were analyzed.

Speech samples for the picture description and monologue tasks were digitized onto a desktop computer at a rate of 22 kHz using speech analysis software (CSpeech Version 4; Milenkovic & Read, 1992) and then dubbed onto cassette tapes (separate tapes for each task) in random order for perceptual analysis. Approximately 20-s segments were selected for the tapes. Each participant was represented once for each task, so that there were 32 speech samples on each of the two tapes. In addition, a "sampler" tape of 12 speech samples was made to expose the listeners to the full range of speech severity across participants. Included were samples from 8 PD and 4 control participants, 6 from each of the two tasks, and 3 from women (weighted to the proportion of women in the study). Selected to reflect the full range of speech severity, the samples were randomly ordered on the tape. Familiarizing listeners with the samples can improve reliability, reduce bias, and scale the endpoints (Schiavetti, 1992).

Eight speech-language pathologists (SLPs), each with at least 5 years' experience working clinically with neurogenic populations, served as listeners for the perceptual study. They were informed that some of the speakers had a speech disorder (unspecified) and some did not. Speech samples were to be judged for articulatory precision ("accuracy and preciseness of the speech articulation") and overall speech ("all aspects of the signal, including articulation, resonance, voice, prosody, and any other characteristics that affect the speech") on a 7-point equal-appearing-interval scale (1 = normal and 7 = severe deviation from normal; Darley, Aronson, & Brown, 1975). The listeners were encouraged to use the whole scale. Before beginning the task, the listeners heard the sampler tape. They then began the perceptual task by rating the speech samples from the picture description (picture provided) and monologue tasks; the order was alternated between listeners. Judgments were made immediately after hearing each sample once; revisions were not allowed. Interrater reliability was assessed with intraclass correlation coefficients, which were .77 for articulatory precision and .82 for overall speech.

Interpause speech rate was analyzed for the picture description and monologue tasks by measuring the duration of the speech samples from the digitized files, subtracting pauses >250 ms (Goldman Eisler, 1968; Solomon et al., 1995), and dividing by the number of syllables produced. Seven (11%) randomly selected speech samples (4 PD, 3 control; 4 picture description, 3 monologue) were remeasured later. When remeasured by the original rater, the values differed by an average of 1.5% (range 0–5.2%); for a new rater, the difference was 2.0% (range 0–6.5%).

Statistical Analyses

Strength and endurance data for the tongue and hand were analyzed with a repeated-measures multivariate analysis of variance (MANOVA). Group (PD and control) was defined as a within-subjects factor to allow for paired comparisons of matched participants. (For a discussion of paired comparison designs, see Montgomery, 1991, Section 2-5.) Follow-up univariate analyses of variance (ANOVA) for each structure (tongue and hand) and function (strength and endurance) were conducted. Stability was reflected by the coefficient of variation ($CV = SD/M$) of five 3-s segments of all endurance trials that were at least 15 s in duration, as explained previously. *CV* data were analyzed with a repeated-measures ANOVA, with structure and segment as the within-subjects factors. Including segment as a within-subjects factor allowed examination of differences in stability over the five segments of the trial. Structure was included as a within-subjects factor to compare hand versus tongue stability within individuals. For this analysis, group was a between-subjects factor to reduce the number of missing cases (due to several trials deleted from statistical analysis because of durations <15 s; see Table 2). Interpause speech rate was tested with a repeated-measures ANOVA, with group as a within-subjects factor—again to maintain pairing between PD and control participants.

Perceptual judgments by the eight SLPs were averaged to derive numerical results for each participant. Four average scores were obtained for each subject, corresponding to articulatory precision and overall speech for each task (picture description and monologue). These scores were then averaged for each participant. Because articulatory precision was represented in both judgments, this average value provided a general indication of severity of speech disorder with an emphasis on (or weighted for) articulatory precision. Participants were ranked on the basis of these averaged perceptual scores and were labeled with the letters A through P accordingly. That is, in the presentation of the results, PD participant A had the least and participant P had the most severely disordered speech. Associations among disease severity, tongue function, perceptual characteristics of speech, and interpause speech rate were assessed with Spearman rank correlations. The alpha level selected to indicate statistical significance for all analyses was .05.

Retrospective Analyses

To increase statistical power for the MANOVA and to increase the range of values for correlational analyses, analyses were repeated with all available data from this and previous studies. For tongue and hand strength and endurance, participant pairs (matched PD and control) included 15 from the present study (Pair P was eliminated because of a missing datum), 19 from the previous study (Solomon et al., 1995), and 1 pair that was eliminated from the previous study because the severity of PD was too great (Hoehn & Yahr Stage 4) to meet selection criteria. This participant demonstrated tongue and hand strengths of 28 kPa and 101 kPa and tongue and hand endurances of 29 s and 16 s, respectively (data for matched control: 76 kPa, 140 kPa, 28 s, 62 s). Pressure (strength) results from the previous study were multiplied by 0.87 to account for differences in tongue bulbs (see Method).

Table 2. Results for strength and endurance of the hand and the tongue for the participants with Parkinson disease and the matched control participants.

	Parkinson disease				Control			
	Strength (kPa)		Endurance (s)		Strength (kPa)		Endurance (s)	
Participant	Tongue	Hand	Tongue	Hand	Tongue	Hand	Tongue	Hand
A	47	109	22.4	61.8	76	86	23.3	44.3
B	55	106	17.0	45.7	62	176	27.1	57.7
C	55	168	31.2	68.0	50	147	52.6	41.8
D	27	135	13.2	39.5	57	133	25.4	54.6
E	53	119	14.9	76.7	60	140	51.6	54.2
F	51	166	21.1	49.1	55	146	36.5	49.4
G	53	168	33.3	79.0	58	154	31.3	61.1
H	62	92	50.0	119.4	46	81	34.5	30.7
I	42	158	12.9	70.5	53	152	32.0	79.3
J	49	112	27.3	41.1	44	97	19.9	86.2
K	44	111	16.4	41.6	50	104	44.9	136.0
L	56	165	12.4	66.7	54	156	59.8	53.0
M	59	137	23.7	57.9	57	125	51.7	67.5
N	48	125	37.8	6.9	41	106	39.7	24.1
O	31	125	8.4	37.0	54	107	33.9	59.7
P	38	81	n.a.	30.8	71	136	25.5	31.5
M	48.1	129.8	22.8	55.7	55.5	127.9	36.9	58.2
SD	9.7	28.3	11.4	25.5	9.1	27.9	12.1	26.6

Spearman rank order correlations for perceptual and temporal characteristics of speech and tongue function included data from the 16 participants with Parkinson disease from this study, 19 from the earlier study, and the 1 PD participant eliminated from the previous study (on a 0–5 scale, overall speech defectiveness and articulatory imprecision were 2.5 and 1.75, respectively; interpause speech rate = 4.55 syllables/s). Perceptual judgments from the previous study (0–5 scale) were recalculated to be comparable to the present 7-point scale.

Results

Strength and Endurance

Results for strength and endurance of the tongue and hand for each participant are given in Table 2. PD participant P was unable to provide a valid measure of tongue endurance because of poorly fitting dentures. Consequently, data from 15 participant pairs were available for analysis. MANOVA revealed a significant main effect for structure [$F(2, 13) = 92.85$, $p < .001$], such that strength and endurance were greater for the hand than the tongue. No group effect was detected [$F(2, 13) = 0.989$, $p = .398$], nor did group interact with structure [$F(2, 13) = 2.224$, $p = .148$]. To explore whether significant differences between groups would be obtained with fewer variables, separate ANOVAs were conducted for the tongue and hand. Tongue endurance was significantly less for PD than control participants [$F(1, 14) = 11.070$, $p = .005$], but no group differences were detected for tongue strength [$F(1, 14) = 2.755$, $p = .119$], hand endurance [$F(1, 14) = 0.063$, $p = .805$], and hand strength [$F(1, 14) = 0.890$, $p = .362$]. Analysis of current data combined with retrospective data revealed group differences for both strength and endurance (Table 3). These differences were attributed to the tongue but not the hand.

Stability

Figure 1 illustrates average *CV* across participants within each group and for each structure; error bars indicate one *SD* of the mean *CV* for each group and structure. Instability during the endurance task differed for the tongue and the hand [$F(1, 22) = 154.3$, $p < .001$], such that the tongue was substantially less stable. There was no statistically significant difference between groups [$F(1, 22) = 0.011$, $p = .918$], nor was there an interaction between structure and group [$F(1, 22) = 0.216$, $p = .646$]. In addition, there was no statistically significant difference in stability across segments [$F(4, 88) = .792$, $p = .533$]. Therefore, no follow-up pairwise comparisons were conducted.

Speech

The speech of the participants with PD ranged from near normal to moderately severe (Table 4). As a group,

Table 3. Statistical results from multivariate and univariate repeated-measures analyses of variance for 35 participant pairs from two studies combined. (See text for details regarding participant inclusion.)

Variable	*F*	*df*	*p*
Group	4.184	2, 33	.024*
Structure	232.127	2, 33	.000*
Strength only			
Group	5.171	2, 33	.011*
Tongue	9.460	1, 34	.004*
Hand	2.707	1, 34	.109
Endurance only			
Group	3.477	2, 33	.043*
Tongue	7.069	1, 34	.012*
Hand	0.107	1, 34	.745

*$p < 0.05$

their speech articulation was less precise [$F(2, 13) = 9.479$, $p = .003$] and more severely defective overall [$F(2, 13) = 14.978$, $p < .001$] than the control participants. Interpause speech rate (Table 5) did not differ significantly between participant groups [$F(2, 14) = 0.088$, $p = .916$] nor between speech tasks [$F(2, 14) = 0.050$, $p = .951$].

For the participants with PD, no significant correlations were found between tongue function measures and any speech characteristics (Table 6). Furthermore, retrospective analyses that included data from 36 participants with PD who had a wide range of speech defectiveness revealed no significant correlations between speech and nonspeech measures (Table 7).

Discussion

Strength, Endurance, and Stability of the Tongue and Hand

Tongue and hand strength and endurance were tested in persons with PD and compared to matched neurologically normal control participants. The results indicated that tongue endurance was lower than normal in persons with PD but that tongue and hand strength and hand endurance were not. These results differ somewhat from those reported in an earlier study (Solomon et al., 1995), in which participants with generally less severe PD were found to have lower-than-normal tongue and hand strength, but not endurance. However, when the data from the two studies were combined, statistical analysis revealed differences between groups for strength and endurance of the tongue but not the hand. On average, tongue strength was 8.3 kPa lower and tongue endurance was 8.2 s shorter for PD than for control participants. Given the relatively small values for these measures, they represent substantial differences that may be clinically important as well as statistically significant.

Figure 1. Stability of the tongue as indicated by the coefficient of variation for 3-s segments taken from endurance trials. Two to five segments were analyzed from each trial, depending on the duration of the trial. Therefore, 15 control (C) participants' data were included for all five segments; 15 Parkinson (P) participants' data were included for segments 1 and 5, 14 for segment 3, and 10 for segments 2 and 4. Endurance data were missing for participant pair P.

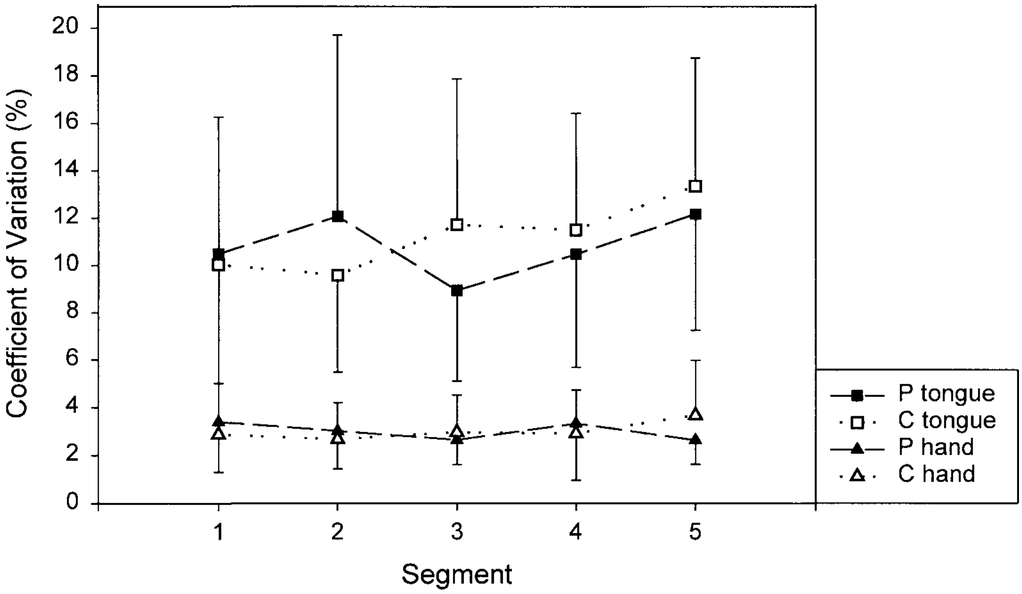

Table 4. Results for the perceptual analyses of speech for articulatory precision and overall speech (average judgments on a scale from 1 = normal to 7 = severe deviation from normal) for the participants with Parkinson disease.

	Parkinson disease					Control				
	Picture		Monologue			Picture		Monologue		
Participant	Articulatory precision	Overall speech	Articulatory precision	Overall speech	Average	Articulatory precision	Overall speech	Articulatory precision	Overall speech	Average
A	1.0	1.5	1.3	2.0	1.4	1.6	2.0	1.1	1.5	1.6
B	1.1	2.4	1.5	1.9	1.7	1.5	1.6	1.4	1.6	1.5
C	1.4	1.9	1.6	2.5	1.8	1.3	1.6	1.3	1.9	1.5
D	1.5	2.0	2.0	2.8	2.1	1.3	1.4	1.1	1.5	1.3
E	2.0	2.6	1.9	2.9	2.3	1.6	1.8	1.8	2.1	1.8
F	2.4	2.8	2.0	2.8	2.5	1.5	1.6	1.1	1.9	1.5
G	2.4	2.9	2.3	2.8	2.6	1.5	2.3	1.3	2.1	1.8
H	1.9	3.0	2.1	3.9	2.7	1.3	2.8	1.4	2.6	2.0
I	2.1	2.8	3.1	3.6	2.9	1.0	1.3	1.4	1.5	1.3
J	2.1	3.9	2.4	3.8	3.0	1.1	1.4	1.3	1.4	1.3
K	1.6	4.3	2.0	4.5	3.1	1.0	1.6	1.4	2.0	1.5
L	3.0	4.5	1.9	3.1	3.1	1.0	1.5	1.1	1.6	1.3
M	3.0	4.3	3.3	4.6	3.8	1.4	2.0	1.0	1.6	1.5
N	3.8	5.1	4.3	5.9	4.8	1.5	2.3	1.9	2.3	2.0
O	4.3	4.6	5.3	5.6	4.9	2.1	2.4	1.9	2.0	2.1
P	5.5	6.3	5.3	6.3	5.8	1.0	1.4	1.3	2.1	1.4

The notion that difficulty with sustained control of the tongue might explain lower-than-normal endurance scores was refuted by the stability analysis. Participants with PD did not demonstrate greater instability than neurologically normal control participants during the endurance task. For both participant groups, motor instability was greater for the tongue than the hand. These results are consistent with those reported by Gentil et al. (1999). In addition, stressing the tongue and hand to the point of fatigue did not lead to decreased stability for the participants with PD or the control participants. These findings contrast with those of Kunesch et al. (1995), who reported decreased stability of finger force maintenance averaged over 30 s for eight participants with PD compared to control participants. This discrepancy between studies could be related to differential effects of basal ganglia dysfunction on the motor control of finger force, handgrip, and tongue elevation. However, this seems unlikely because no interaction between structure (hand and tongue) and participant group (PD and control) was found for stability in the present study. Because of differences in task, instrumentation, data reduction, and data analysis, it is difficult to compare the two studies directly.

Table 5. Interpause speech rate (syllables/second) for the picture description and monologue tasks.

	Parkinson		Control	
Participant	Picture	Monologue	Picture	Monologue
A	4.82	4.66	3.99	4.36
B	4.22	4.36	4.53	4.11
C	5.63	5.29	4.42	4.81
D	4.31	5.13	4.89	4.46
E	4.71	5.22	4.19	3.84
F	5.81	4.83	4.12	4.50
G	4.09	4.17	2.93	3.88
H	2.55	2.76	4.48	4.99
I	4.27	4.63	4.59	4.43
J	4.10	4.73	5.13	4.98
K	3.45	3.51	3.77	3.62
L	4.60	4.65	5.49	4.04
M	3.69	3.47	4.17	5.01
N	4.55	4.80	3.99	4.37
O	5.26	4.66	4.56	4.40
P	4.63	4.27	4.12	3.91
M	4.42	4.45	4.34	4.36
SD	0.80	0.69	0.58	0.44

Other tasks should be considered to examine whether the present findings are specific to the method used. For example, visuomotor tracking of brief (Barlow & Abbs, 1986; Barlow & Burton, 1990; Connor & Abbs, 1991) and continuous (Moon, Zebrowski, Robin, & Folkins, 1993) signals can be instructive for examining nonspeech movements of speech articulators. Connor and Abbs (1991) found that jaw function in persons with PD was normal for natural speech tasks and deficient for nonspeech and visually guided tasks. The novelty of pushing the tongue against the roof of the mouth may invoke a different level of motor control than more familiar tasks (Connor & Abbs, 1991; Gordon, 1998; Ingvarsson, Gordon, & Forssberg, 1997) like squeezing

Table 6. Spearman Rank Correlation coefficients and significance values for perceptual characteristics of speech and interpause speech rate from each speech task correlated with tongue strength and endurance for the participants with Parkinson disease.

		r_s	*p*
Picture description			
Articulatory imprecision	× tongue strength	–.129	.625
	× tongue endurance	–.079	.773
Overall speech defectiveness	× tongue strength	–.100	.705
	× tongue endurance	–.025	.923
Interpause speech rate	× tongue strength	–.272	.298
	× tongue endurance	–.271	.319
Monologue			
Articulatory imprecision	× tongue strength	–.345	.186
	× tongue endurance	.070	.793
Overall speech defectiveness	× tongue strength	–.230	.384
	× tongue endurance	.000	.995
Interpause speech rate	× tongue strength	–.255	.331
	× tongue endurance	–.098	.714

Table 7. Spearman Rank Correlation coefficients and significance values for perceptual characteristics of speech and interpause speech rate from a picture description task correlated with tongue strength and endurance for all available participants with Parkinson disease from previous research and the present investigation (n = 35; see text for details).

		r_s	*p*
Articulatory imprecision	× tongue strength	–.214	.209
	× tongue endurance	.114	.513
Overall speech defectiveness	× tongue strength	–.256	.131
	× tongue endurance	.119	.493
Interpause speech rate	× tongue strength	–.177	.307
	× tongue endurance	.132	.452

a rubber "ball." In addition, visual feedback may (Connor & Abbs, 1991) or may not (Gordon, Ingvarsson, & Forssberg, 1997) interfere with optimal performance.

The findings from the cumulative analysis of present and retrospective data that hand strength and endurance are normal in PD support the exclusion of weakness and fatigue from most clinical descriptions of PD. Studies of normal or greater-than-normal force generation during precision grip between the forefinger and thumb by participants with PD (Ingvarsson et al., 1997; Müller & Abbs, 1990) corroborate the present result of normal handgrip strength. A contributing factor could be that the present participants with PD were optimally medicated. Extensor strength of the elbow (Corcos et al., 1996) and wrist (Brown et al., 1997) were significantly greater when participants with PD were on medications than when they were off medication. These findings, in conjunction with the finding of reduced tongue strength in the present participants with PD, are congruent with the observation that speech does not benefit from levodopa therapy to the same extent as nonspeech functions (Calne, Stern, Spiers, Laurence, 1969; Rigrodsky & Morrison, 1970; Wolfe, Garvin, Bacon, & Waldrop, 1975).

Relation Between Tongue Function and Speech

No significant correlations were found among tongue function, perceptual judgments of speech, or speech rate for the participants with PD from the present study or when these data were combined with previously available data. It is possible that the equal-appearing-interval scale selected for assessing perceptual characteristics of speech was not sensitive to differences and that another scaling method such as direct magnitude estimation might have been more successful (e.g., Schiavetti, Metz, & Sitler, 1981). However, one common problem with interval scales, the constraint of endpoints, was avoided by exposing the listeners to the full range of severity among the samples before starting the task. Moreover, other studies that have found significant correlations between tongue strength and severity of dysarthria employed interval scales (DePaul & Brooks, 1993; Dworkin et al., 1980; Langmore & Lehman, 1994; Stierwalt et al., 1995). A methodologic consideration for speech rate was whether or not to include pauses. To evaluate this issue, potential correlations between tongue function and speech rate *including* pauses were examined, but again, none were significant. In this report, interpause speech rate was selected as the more specific measure for evaluating the particular effects of impaired tongue function on speech. In addition, it allowed for direct comparison with the previous study (Solomon et al., 1995).

A plausible explanation for the lack of correlation between the speech and nonspeech measures is that reduced tongue strength may need to reach a critical level before detrimental effects on speech are perceived (Robin et al., 1992; Robin, Solomon, Moon, & Folkins, 1997). For speech purposes, the operating range for orofacial structures appears to be relatively small (~10–25% of maximum; e.g., Barlow & Burton, 1990; Muller, Milenkovic, & MacLeod, 1984, cited by Langmore & Lehman, 1994). Therefore, one might assume that mildly to moderately reduced tongue strength would not impinge on the force levels needed for adequate speech. However, because this results in a reduced reserve (DePaul & Brooks, 1993; Kent, Kent, & Rosenbek, 1987), speech might be more effortful to produce and prone to breakdown.

Although tongue strength and endurance in PD appear not to be impaired to the extent that speech would be degraded, research addressing other neurogenic disorders may be revealing. Tongue weakness is a hallmark of ALS (DePaul & Brooks, 1993; Langmore & Lehman, 1994). Langmore and Lehman (1994) found tongue weakness even in persons with the spinal form of ALS who demonstrated no clinical signs of bulbar or corticobulbar involvement. This supports the notion that certain levels of weakness are tolerated by the speech system. Significant positive correlations between severity of dysarthria and tongue strength in ALS were reported [$r = -0.66$ in DePaul & Brooks, 1993; $r = -0.628$, according to Table 4 in Langmore & Lehman, 1994 (discrepancy in text)]. Barlow and Abbs (1986) studied adults with congenital spastic cerebral palsy and found reductions in the rate of force change by orofacial structures (jaw, upper and lower lips, and especially tongue) to be associated with reduced speech intelligibility. They also documented substantial orofacial motor impairments in some participants who had completely intelligible (but not necessarily normal) speech. Admittedly, intelligibility is not a sensitive measure of speech defectiveness (cf. McHenry et al., 1994; Stierwalt et al., 1995) and, as stated by DePaul and Brooks (1993), it "may be the best indicator of how well the speech production system can preserve function in the presence of quantifiable weakness" (p. 1165).

Although the studies discussed do not answer the question of the critical level of weakness for speech impairment, they do provide convincing evidence that a substantial level of weakness will impact speech. The "threshold" of weakness for resulting functional impairment may not be a straightforward value. Presumably, it is affected in a complicated way by the number of structures affected in the speech-production system, the relative degree of involvement of each structure, the nature of the weakness, individual capabilities for flexibility and compensation, influences of stress on the system, and other yet-undetermined factors.

Whether oromotor function correlates with speech is a topic of ongoing investigation. Other speech samples collected from the participants in this study are being analyzed in detail for acoustic (temporal and spectral) properties and will be reported subsequently. These analyses should allow a better understanding of the relation between speech and nonspeech functions of the same muscular structure.

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