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Kinematic and correlational analyses on labial and lingual functions during syllable repetitions in Cantonese dysarthric speakers with Parkinson's disease of varying severity using electromagnetic articulography (EMA)

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Abstract

Articulatory imprecision in Parkinson patients with hypokinetic dysarthria has been attributed to articulatory undershooting. However, contradictory results in terms of acoustics and instrumental investigation has been reported in the literature throughout the years. The present study aimed to investigate labial and lingual kinematics in dysarthric Cantonese speakers with Parkinson's disease (PD) of different severity (in terms of dysarthria) during rapid syllable repetitions and compared the measures with that of healthy age-matched controls using a 3-dimensional Electromagnetic Articulography (EMA). Dysarthria severity was also correlated with labial and lingual kinematics. Tongue tip, tongue back, upper and lower lips and jaw motion in five PD and six normal participants during repetitions of /pa/, /ta/ and /ka/ were recorded. Participants were also rated perceptually on their dysarthria severity. When compared to the normal group, the PD group showed reduced velocity in lingual movement and reduced distance travelled and velocity in labial movements. Correlational analysis between dysarthria severity and kinematic data revealed positive correlation for duration of lingual movement. Negative correlation was identified for the velocity and rate of lingual movement, and for distance travelled and velocity of labial movement. The present results supported the hypothesis of articulatory undershooting as a contributing factor of articulatory imprecision in hypokinetic dysarthria, while tongue and lip tremor might also cause such consonant imprecision. Possible differential effect of dopamine deficiency on the different cranial nerves has been hypothesized.

Keywords: Parkinson's disease, kinematics, syllable repetition, electromagnetic articulography

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Introduction

Parkinson's disease (PD), also known as idiopathic Parkinsonism, is a progressive neurodegenerative disease with incidence generally beginning in the older adults and affecting more males than females (Fahn, 2003). Symptoms of PD include resting tremor, bradykinesia, rigidity, postural instability and freezing phenomenon (Fahn, 2003; Jankovic, 2008; Marigliani & Gates, 1997). Dopamine deficiency, brought about by a degeneration of the dopaminergic neurons in the pars compacta of substantia nigra, mainly accounts for the hallmark features of bradykinesia and rigidity in PD, and the symptoms would gradually become more severe as dopamine concentration declines with the progression of the disease (Fahn, 2003).

In addition to problems in gross motor functions, PD patients also suffer from "hypokinetic dysarthria" (Darley, Aronson, & Brown, 1969a, 1969b, 1975), which can impact on all areas of the speech production mechanism including respiration, phonation, resonance and articulation. This results in PD speech with reduced stress, monopitch, reduced loudness, monoloudness, articulatory imprecision, variable speech rates and short rushes of speech (e.g., Darley et al., 1969a, 1969b, 1975; Duffy, 2005). Perceptual characteristics of hypokinetic dysarthria in the Cantonese population has been investigated, and the results were largely consistent with the findings of Darley et al. (1969a, 1969b), with voice, prosody and articulation as the most affected speech dimensions (Ma, Whitehill, & Cheung, 2010; Whitehill, Ma, & Lee, 2003). Among the dimension of articulatory impairment, consonant imprecision was found to be most significant and common in the PD population with

hypokinetic dysarthria (Darley et al., 1969a, 1969b, 1975; Logemann, Fisher, Boshes & Blonsky, 1978). Darley et al. (1975), and Ackermann and Ziegler (1991) attributed such consonant imprecision to the limited range of movement, muscle rigidity and bradykinesia, which is similar to that found in the limbs of the individuals with PD.

Acoustic studies on dysarthric speech of PD appeared to support Darley et al.'s hypothesis (Duffy, 2005). One such evidence came from Ackerman and Ziegler (1991), who reported spirantization of stops as a frequent error observed among speech of the PD participants. Spirantization involves the replacement of stop gaps during plosives and affricates with frication resulted from a failure in forming a complete articulatory closure (Kent & Rosenbek, 1982; Weismer, 1984). Numerous acoustic studies have documented spirantization during the production of stops and affricates as an evidence for articulatory undershooting (e.g., Ackermann, Hertrich, & Hehr, 1995; Canter, 1965; Kent & Rosenbek, 1982; Weismer, 1984; Ziegler, Hoole, Hartmann & Cramon, 1988). The presence of spirantization therefore suggested articulatory undershooting as a feature of dysarthric speech in PD.

However, perceptual and acoustical investigations alone are not sufficient to evidence the underlying pathophysiology of motor speech disorders (Duffy, 2005). Several research studies utilized physiological assessment techniques in investigating the articulators of PD individuals, but the results were largely diverse. A quantitative analysis revealed increased muscle tone accompanied by a reduced range of movement of the lower lip and it was hypothesized that hypokinesia was the underlying cause of labial rigidity (Hunker, Abbs & Barlow, 1982). Another analysis on the speech of PD and normal elderly through perceptual, acoustic and kinematic methods found that PD speakers' lip and jaw movement range and velocity were reduced for opening gesture while that of closing gestures were increased (Forrest, Weismer, & Tuner, 1989). It was also documented that PD patients showed a

reduction in tongue force and endurance (Dworkin & Aronson, 1986; Solomon, Robin, & Luschei, 2000). However, these data were obtained through non-speech tasks and might not truly reflect the performance of the participants during speech. Other studies made use of electropalatography (EPG) to investigate speech patterns in PD individuals (McAuliffe, Ward & Murdoch, 2005, 2006a, 2006b). However, results varied, ranging from similar tongue-to-palate contact patterns between PD individuals and normal controls (McAuliffe et al., 2006a); perceptually but not objectively identified impaired speech rate (McAuliffe et al., 2006b) to reduced tongue-to-palate contact and impaired tongue control (McAuliffe et al., 2005). Further kinematic data on the lingual movement of PD individuals during speech tasks are needed to draw a clearer picture of the articulatory disturbances in this population. Electromagnetic articulography (EMA) is a technique that could obtain such data.

EMA is a biologically safe and non-invasive technique that utilizes principles of electromagnetism to track and record movements of the articulatory structures, including the tongue and lips, with high reliability and it provides real-time three-dimensional kinematic data without interfering speech production (Hoole & Nguyen, 1999; Horn, Göz, Bacher, Müllauer, Kretschmer & Axmann-Krcmar, 1997; Murdoch, 2011; Tang, Ng, Chen, & Yan, 2012; Yunusova, Green, & Mefferd, 2009). Several studies investigated tongue function in PD individuals utilizing EMA (Ackermann, Gröne, Hoch, & Schönle, 1993; Wong, Murdoch, & Whelan, 2010a, 2010b, 2011, 2012).

Syllable repetition tasks, also known as diadochokinetic (DDK) tasks, have been widely used as perceptual speech tasks for different kinds of motor speech disorders. DDK tasks allow assessment on the speed and regularity of the repetitions, articulatory precision, velopharyngeal competence and respiratory support during rapid repetitive articulatory movements (Duffy, 2005). Ackermann et al. (1993) documented occurrences of speech freezing, in which repetition rates were increased whereas lingual movement amplitudes were

reduced, during repetition of /ta/ syllables in an akinetic-rigid dysarthric woman with PD. These kinematic findings were attributed to the hypothesis of articulatory undershoot in individuals with PD (Ackermann & Ziegler, 1991; Darley et al., 1975) by the authors.

In contrast, Wong et al. (2012) reported that both dysarthric and non-dysarthric PD groups had increased range and duration, increased velocity, acceleration and deceleration of lingual movement during repetitions of /ta/ and /ka/ which contradicted with the hypothesis of articulatory undershoot accounting for the articulatory imprecision in hypokinetic dysarthria. Findings of Wong et al. (2010a, 2010b, 2011), which made use of sentence production tasks in examining tongue function in PD individuals, also contradicted this hypothesis. However, their PD participants were only mildly dysarthric and thus the odds of identifying significant differences in the lingual kinematic data between the dysarthric PD group and normal control group would be reduced (Wong et al., 2010a, 2010b, 2011, 2012).

Owing to the contradictory findings, further studies investigating lingual kinematics in dysarthric speakers with PD would shed light to the neuropathophysiological basis of hypokinetic dysarthria. In addition, to date, no kinematic analysis on the articulation of PD individuals in the Hong Kong Cantonese-speaking population has been carried out. The present study therefore aims to investigate labial and lingual kinematics in dysarthric Cantonese speakers with PD of different severity (in terms of dysarthria) during rapid syllable repetitions and compare the measures with that of healthy age-matched controls using a 3-dimensional EMA. It is hypothesized that (a) the PD group will exhibit deviant performances in terms of labial and lingual kinematics when compared to that of normal controls; (b) there will be a correlation between severity of the hypokinetic dysarthria and lingual and labial kinematics data.

Method

Participants

A total of 11 native Cantonese speakers of Hong Kong (see Table 1) were recruited to participate in this study, consisting of five PD speakers (PD group) and six healthy speakers (Normal group), aging from 50-80 years old. Only PD patients who were on levodopa medication were recruited. Exclusion criteria included a history of neurological condition other than PD, speech and language disorders, hearing impairment, hypersensitivity to magnetic fields, implanted metallic and electronic devices (such as pacemakers) that could not be removed during the assessment and surgeries involving oral-facial structures.

Table 1

Demographic Data of Participants from the Normal (N) and PD group

Participant number	Age	Gender	Dysarthria rating (1-9)	Hoehn and Yahr scale
N001	54	M	1	-
N002	60	M	1	-
N003	62	M	1	-
N004	53	F	1	-
N005	75	F	1	-
N006	56	M	1	-
PD001	53	M	1	2
PD002	69	M	3	2
PD003	67	F	4	2
PD004	77	M	2	3
PD005	78	F	2	2.5

Instrumentation

A 3D EMA system (AG500, Carstens Medizinelektronik GmbH, Germany) was used to obtain real-time kinematic data of tongue and lip movement during syllable repetition. Eight receiver coils were set up, including three for references: 1) nasal bridge, 2) mastoid process of the left ear, and 3) mastoid process of the right ear. The other five sensors were placed along the midline of tongue at 1 cm and 4 cm from the tongue tip, and of the upper

and lower lips and jaw. The most anterior sensor coil on the tongue was placed 1 cm behind the tongue tip to avoid any irritation that might affect speech production (Hoole & Nguyen, 1997). All sensors were placed at least 1 cm apart to prevent possible interference. A microphone (SM58, Shure) was used to obtain acoustic signals from the participant's speech.

Procedure

The EMA system was first calibrated according to the operators' menu for each set of sensors (8 sensors/participant). The two sensors used for tongue measurements were coated in latex and dried overnight. Prior to each experiment, the EMA system was switched on for at least 1 hour to allow the system to reach an appropriate working temperature. PD patients were required to take their prescribed medication 1.5 hour before the assessment. During the assessment, the participants were required to remove all metallic and electronic items and sit in a straight-back chair inside the EMA cube. Eight sensors were attached to the articulators with biologically-safe adhesive. The experimenter then engaged in casual conversation with the participants for at least five minutes to allow participants to familiarize themselves with the sensors. The participants were then instructed to repeat the syllables /pa/, /ta/ and /ka/ at their fastest speed in a single breath with the highest articulatory precision they could maintain. A total of five trials for each task (5 trials x 3 tasks) were recorded. A total of four sets of DDK tasks were made through randomization of the 15 trials and the participants were assigned to their DDK list according to their participant number.

All speakers were also required to read a passage. The speech sample recorded was subsequently rated by a practicing speech therapist, who was experienced in perceptual speech ratings and blinded of the neurological status of the participants, to identify the presence and severity of dysarthria. The severity ratings were given based on a 9-point scale (1 = non-dysarthric, 9 = severely-dysarthric) the respective ratings could be seen in Table 1.

Data analysis

The three different DDK tasks were analyzed according to their place of articulation. Therefore, kinematic data for the lower lip, tongue tip, and tongue back and would be extracted from the repetition of /pa/, /ta/, and /ka/ respectively. Movement of upper lip was not included because of its limited movement during the repetition tasks. Each of the kinematic measures was subtracted from that obtained from the jaw. As a result, only the net movement of the respective articulator was obtained.

For each participant, one train of three consecutive syllable repetitions which were free of errors was extracted from each of the five trials, making a total of five trains. The EMA signals were amplified and digitized at 200 Hz and evaluated by a processing unit. The recorded data were then analyzed by using the *CalcPos* program to obtain the kinematic data of the sensors' motion. Head movement adjustment was later carried out by using the *NormPos* program with inputs from the reference sensors.

Based on the protocol developed by Wong et al. (2012), kinematic measures included seven parameters, including distance travelled, duration of production, and average velocity of the lower lip, tongue tip and tongue back for both the approach phase and release phase during the syllable repetition, and the overall rate of syllable repetition. The approach phase is defined as the tongue movement to the palate or lip movement to yield lip contact while release phase is defined as the tongue movement away from the palate or lip movement during lip separation. The approach phase (A to B) and release phase (B to C) were identified by identifying the lowest (A, C) and highest points (B) of the z-displacement curves (see Figure 1) obtained through the EMA.

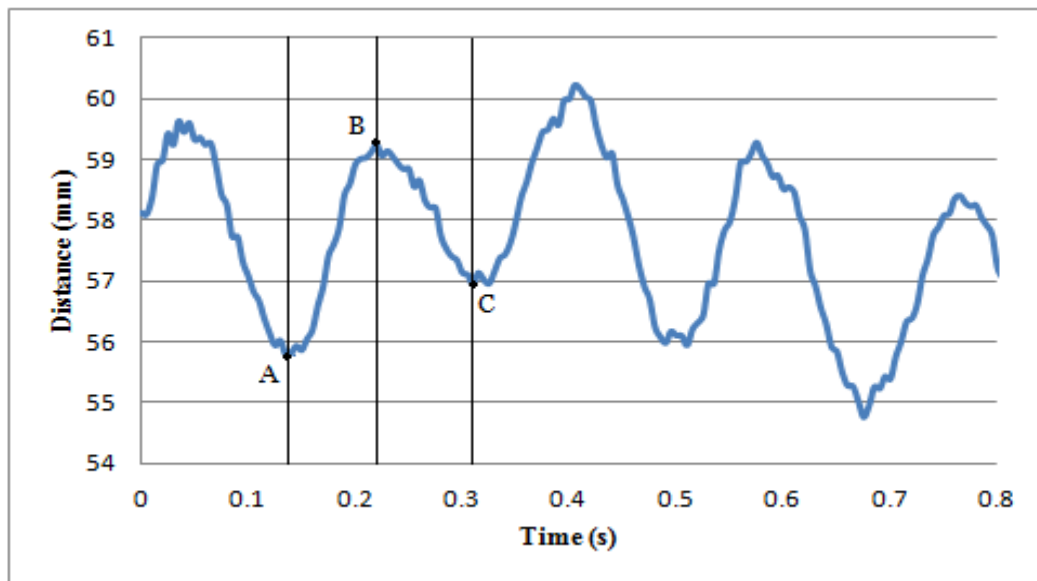


Figure 1. Tongue tip movement during repetition of /ta/ by a normal participant.

Statistical analysis

As a small and unequal sample size was used in this study, a non-parametric statistical analysis, the Mann-Whitney U test, was used for comparison between the PD and control groups with respect to the three places of articulation (tongue back, tongue tip, lower lip), for the approach and release phase separately. A correlational analysis using the non-parametric Spearman rho was also conducted between the severity of dysarthria and each of the kinematic measures on the three different places of articulations, for the approach and release phase separately for all the participants. A preset significance level of 0.05 was used.

Results

The mean and standard deviation values of kinematic data of the PD group and the normal group obtained are shown in Tables 2 to 4.

Mann-Whitney U test revealed no significant differences between normal and PD groups, except for the average velocity during the release phase of the repetition of /ka/ at the tongue back and across all kinematic measures during the approach and release phase of the

repetition of /pa/ for the lower lips apart from duration and rate. No significant difference was identified for any of the kinematic measure for the repetition of /ta/ for the tongue tip.

The PD group was found to have a significantly lower average velocity during the release phase of the repetition of /ka/ ($U = 2, p = .017$) than the normal group. During the approach phase of /pa/ repetition, the PD group was found to have a significantly shorter distance travelled ($U = 0, p = .004$) and slower average velocity ($U = 1, p = .009$); while for the release phase of /pa/ repetition, similar results were identified, with shorter distance travelled ($U = 0, p = .004$) and slower average velocity ($U = 0, p = .004$).

Spearman correlational analysis revealed a significant and strong positive correlation between dysarthria severity and duration of release phase during repetition of /ka/ [$r_s(9) = .766, p = .006$]; significant and moderately positive correlation between dysarthria severity and duration of approach phase during repetition of /ta/ [$r_s(9) = .628, p = .038$].

A significant and strong negative correlation was identified between dysarthria severity and rate of repetition of /ta/ [$r_s(9) = -.718, p = .013$]; distance travelled [$r_s(9) = -.813, p = .002$] and average velocity [$r_s(9) = -.750, p = .008$] of approach phase and distance travelled [$r_s(9) = -.813, p = .002$] and average velocity [$r_s(9) = -.850, p = .001$] of the release phase during repetition of /pa/.

Finally, a significant and moderate negative correlation was identified between dysarthria severity and the average velocity of the approach [$r_s(9) = -.623, p = .041$] and release phase [$r_s(9) = -.660, p = .027$] during repetition of /ka/ respectively.

Table 2

Mean (Standard Deviation) Values of Kinematic Measures during the Approach Phase of Repetitions of /pa/, /ta/, and /ka/ of Normal group and the PD group

	Approach phase		
	Distance travelled (mm)	Duration (ms)	Average velocity (mm/s)
<i>Repetition of /pa/</i>			
Normal group	5.35 (2.04)	76.35 (14.22)	80.38 (40.16)
PD group	1.75 (0.57)	86.65 (35.21)	25.96 (13.94)
<i>Repetition of /ta/</i>			
Normal group	5.66 (3.46)	77.94 (10.61)	78.90 (50.69)
PD group	2.59 (1.33)	92.80 (15.75)	33.85 (17.85)
<i>Repetition of /ka/</i>			
Normal group	5.67 (3.11)	82.31 (3.00)	71.17 (37.86)
PD group	2.78 (1.39)	87.00 (16.35)	35.67 (17.28)

Table 3

Mean (Standard Deviation) Values of Kinematic Measures during the Release Phase of Repetitions of /pa/, /ta/, and /ka/ of Normal group and the PD group

	Release phase		
	Distance travelled (mm)	Duration (ms)	Average velocity (mm/s)
<i>Repetition of /pa/</i>			
Normal group	5.33 (2.06)	96.17 (18.37)	63.08 (21.21)
PD group	1.65 (0.50)	102.35 (20.29)	19.74 (6.17)
<i>Repetition of /ta/</i>			
Normal group	5.50 (3.36)	87.89 (7.12)	67.76 (38.74)
PD group	2.58 (1.25)	89.34 (9.61)	35.31 (21.81)
<i>Repetition of /ka/</i>			
Normal group	5.51 (2.80)	83.90 (6.58)	68.48 (34.42)
PD group	2.80 (1.34)	99.60 (13.65)	30.32 (13.04)

Table 4

Mean (Standard Deviation) Rate of Repetitions of /pa/, /ta/, and /ka/ of Normal group and the PD group

	Rate (syllables per second)
<i>Repetition of /pa/</i>	
Normal group	6.12 (0.62)
PD group	5.67 (1.07)
<i>Repetition of /ta/</i>	
Normal group	6.13 (0.47)
PD group	5.60 (0.54)
<i>Repetition of /ka/</i>	
Normal group	6.12 (0.24)
PD group	5.75 (0.96)

Discussion

Comparable kinematic data were obtained for both the repetitions of /ta/ and /ka/ (except for the average velocity during the release phase of /ka/ repetition). Significant differences were identified for lower lip kinematics including the range and average velocity during repetition of /pa/ for both approach and release phases. These findings are in line with those reported by Hunker et al. (1982), in which reduced range of movement of lower lip was found. The duration and rate of repetitions were comparable between the two speaker groups which are similar to the previous findings of comparable DDK rates between PD group and normal group (Tjaden & Watling, 2003; Ziegler, 2002). It appears that PD participants showed a similar extent of reduction in both range and velocity, thus resulting in a comparable duration and rate with the normal speakers for the repetition of /pa/.

The reduction in range and velocity in lip movement during /pa/ repetition and reduced velocity during the release phase of /ka/ repetition provides support for the hypothesis of articulatory undershooting and bradykinesia underlying the nature of

hypokinetic dysarthria in PD patients by Ackermann and Ziegler (1991) and Darley et al. (1975). Articulatory undershoot refers to the reduction in the amplitude of articulatory movement. Such behavior, apart from being related to the motor deficits caused by dopamine deficiency, has also been hypothesized to be a compensatory method for the PD patients in order to maintain normal speech rate (Kent & Rosenbek, 1982). The present data seem to agree with both hypotheses since it was found that the range and velocity for the oral motor structure were reduced while the rate was not largely affected during the DDK tasks. In fact although no significant differences were identified, the PD group did exhibit a reduction in the mean distance travelled and velocity, with lengthened duration in approach phase and release phase during all DDK tasks (see Table 2-3). The lack of statistical significance for the kinematic data during repetitions of /ka/ and /ta/ might be related to the great individual variability (see Table 2-4), small sample size and the PD group with relatively mild dysarthria, leading to a reduced likelihood of revealing significant differences between the PD group and the normal speaker group. The results from the current study were also contradictory to Wong et al. (2012), which reported increased range and speed parameters of lingual movement (tongue tip and tongue back) during repetitions of /ta/ and /ka/. This might be related to the different data analytic method employed. Jaw kinematics were subtracted from that of the respective articulatory structures investigated (lower lip, tongue tip, tongue back) in the present study, whereas the combined effect of both the jaw and the tongue was investigated in Wong et al.'s study.

Correlational analysis of perceptual rating of the dysarthria severity and the kinematic data revealed significant and positive correlation for duration, and significant and negative correlation for the distance travelled, rate and velocity by the articulators during DDK tasks. These results suggest that severe hypokinetic dysarthria is associated with longer duration, shorter distance travelled, rate and velocity during these DDK tasks, providing further

support to the hypothesis of articulatory undershooting due to dopamine deficiency, which is similar to the rigidity and bradykinesia found in the trunks of PD patients. Rigidity and bradykinesia due to dopamine deficiency are hallmark features of PD and result in the slowness and limited range of movement in the limbs of PD patients. (Fahn, 2003). The same restricted range and slowness was observed in the oral motor structures in this study, therefore, future research should aim at identifying any causal relationship between dopamine deficiency and the articulatory undershooting phenomenon in PD patients with dysarthria to confirm this hypothesis.

Further qualitative analysis of the movement waveforms of PD participants also provided another explanation for the characteristics of hypokinetic dysarthria. The DDK waveforms associated with the PD speakers were largely irregular (see Figure 2), reflecting a reduced control over and slight tremor of the tongue and lips, which might not be observable through visual observation. Indeed, tremor has been reported to affect both the tongue and lips in PD patients (Jankovic, 2008).

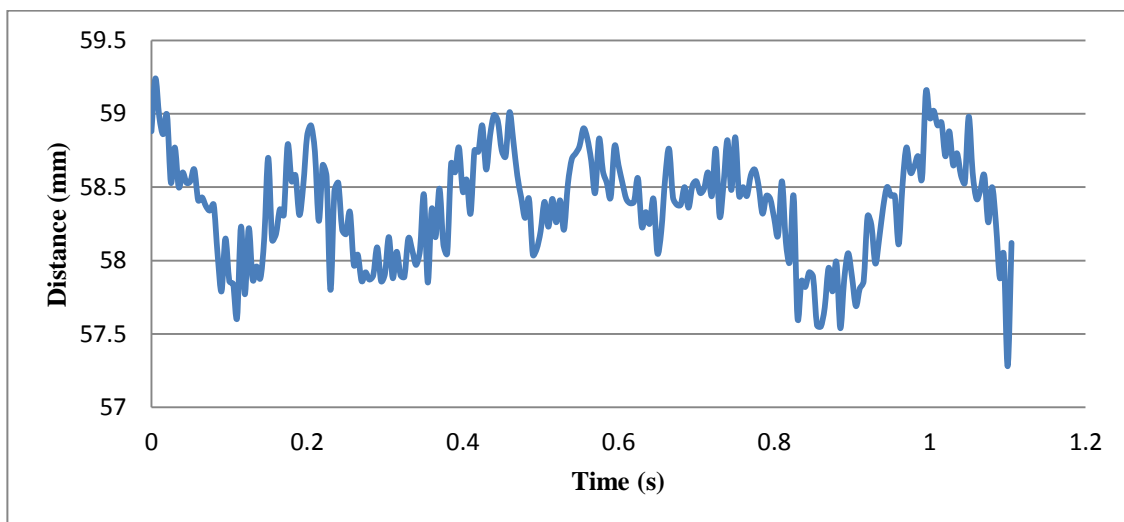


Figure 2. Tongue back movement with tremor-like motion during 5 repetitions of /ka/ by a PD participant.

The tremulous movement of articulators may negatively affect PD patients' speech accuracy and stability, rendering productions with great perturbation and irregularity. This

can be revealed by EMA measurements of articulators of PD patients during speech (see Figure 2). Therefore, consonant imprecision might be contributed by rigidity, bradykinesia and a reduced control of the tongue and lips.

In addition, significant differences identified in lower lip kinematic but not tongue tip and back might also reflect the underlying pathophysiology of the disease. Masked face, an early feature of Parkinson's disease, has been related to the bradykinesia of the intentional facial movements (Bowers, Miller, Bosch, Gokcay, Pedraza, Springer, & Okun, 2006). Facial muscles are innervated by facial nerve (CN. VII). The repetition of /pa/ involves the voluntary control of the lips, which is also innervated by the facial nerve. Therefore, attributing bradykinesia as the underlying cause of the reduced range and velocity of the lips, thus consonant imprecision seems reasonable. Yet, in the present study, only significant findings were identified for labial but not lingual kinematics (except for the average velocity for the release phase of the repetition of /ka/). This might reflect a differential effect of dopamine deficiency via the different cranial nerves innervating different oral motor structures. Braak et al. (2003) also reported that various brain sites vary in their susceptibilities in developing PD-related alterations. Therefore, it would be likely that different degrees of reduction in range and speed of movement of the articulators would be resulted. Based on the findings of the present study, dopamine deficiency might affect facial nerve (CN. VII), which innervates the lips, more than hypoglossal nerve (CN. XII), which innervates the tongue. This concept might further imply that among all other consonants, labial consonants would be the first to be affected in people with Parkinson's disease and would be a stronger indicator of a motor speech problem.

However, in a perceptual analysis by Logemann et al. (1978), out of 200 PD patients, 45% were identified to have laryngeal dysfunction only; 13.5% with laryngeal and tongue-back dysfunction; 17% had laryngeal, tongue-back and tongue-blade dysfunction;

5.5% with laryngeal, tongue-back, tongue blade and labial problems; and 9% with laryngeal dysfunction and misarticulations of tongue-back, tongue-blade, tongue-tip and lips. Logemann et al. (1978) therefore suggested a posterior to anterior progression of dysfunction of the articulators, beginning from laryngeal system, posterior tongue and then the more anterior portion of the tongue and finally affecting the lips. This finding seems to be in contradiction with the current speculation. Yet, as suggested by Adams and Dykstra (2009), a similar reduction in the mobility of different oral motor structures might result in different severity of articulatory problem. Therefore, although lower lip kinematics were found to be affected the most in the current study, this significant difference in the motor ability of the lower lip between the normal and PD group might not reduce speech intelligibility as much as the non significant differences identified in tongue tip and tongue back. The results of the present study could thus only lead to speculations of the lower lips being the first to be affected in its motor ability. Apparently future research involving longitudinal studies of speech deterioration of PD speech through both perceptual and instrumental methods such as the EMA should confirm the different conjectures.

Limitations and Future Directions

In the present study, severity of dysarthria was rated perceptually by using a non-standardized 123-word Chinese passage produced by the participants. In Cantonese, a standardized reading passage is lacking. The use of such non-standardized reading passage might not reflect the actual performance of the participant in daily conversations. Further studies are encouraged to include speech samples of spontaneous speech for dysarthria rating.

In addition, this study included only a very small number of participants for both the normal and PD groups. The dysarthria severity of the PD group ranged from normal to moderately severe only. Owing to the huge individual variability identified in the normal

group, future studies involving a greater number of subjects with a larger range of dysarthria severity for the PD group will bring more significant and generalizable results.

It was also noted that the biological adhesive of varying thickness were used in the experiment. This difference might have led to a reduction in the range of movement of the articulators, especially the elevation of the tongue tip during the repetition of /ta/. Therefore, future studies should perhaps standardize the thickness of the biological adhesive to obtain more accurate kinematic data.

Moreover, although DDK tasks have been widely used as an assessment of motor speech disorders, it has been reported by other studies that the results from DDK tasks might not reflect the true performance of the clients during natural conversation (Perkell & Zandipour, 2002; Weismer, 2006). Future studies should include both DDK tasks and sentence tasks for further comparison. It should also be recommended to separately analyze the kinematic data of the jaws during these tasks such that the amount of contribution by the each of the articulators could be identified. Research should also aim at identifying any causal relationship between dopamine deficiency and articulatory undershooting. Longitudinal studies on the speech deterioration of Parkinson patients with dysarthria utilizing both perceptual and instrumental methods will also be required to confirm the hypothesis of lip motor ability, or even labial sounds being affected first, in the present study.

Conclusion

The present study revealed significantly lower average velocity during the release phase of the repetition of /ka/; significantly shorter distance travelled and slower average velocity during the approach and release phases of /pa/ repetition in the PD group when compared to normal controls. Correlational analysis of perceptual rating of the dysarthria severity and the kinematic data also revealed positive significant correlation for duration and

negative significant correlation for the distance travelled, rate and velocity of the articulators during DDK tasks. These findings supported the hypothesis of articulatory undershooting as a contributing factor of articulatory imprecision in hypokinetic dysarthria. Qualitative analysis of the articulatory movement of PD speakers during DDK tasks has also led to speculation of mild or even unobservable tremor, or a reduction of the control, of the articulators as another factor leading to consonant imprecision. It was also hypothesized that dopamine deficiency might have a differential effect on the different cranial nerves and was proposed that the motor ability of the lower lips might be the first to be affected in PD patients.

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