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Speech-related fatigue and fatigability in Parkinson's disease

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Abstract

This study tested the assumption that speech is more susceptible to fatigue than normal in persons with dysarthria. After 1 h of speech-like exercises, participants with Parkinson's disease (PD) were expected to report increased perceptions of fatigue and demonstrate fatigability by producing less precise speech with corresponding acoustic changes compared to neurologically normal participants. Twelve adults with idiopathic PD and 13 neurologically normal adults produced sentences with multiple lingual targets before and after six 10-min blocks of fast syllable or word productions. Both groups reported increasing self-perceived fatigue over time, but trained listeners failed to detect systematic differences in articulatory precision or speech naturalness between sentences produced before and after speech-related exercises. Similarly, few systematic acoustic differences occurred. These findings do not support the hypothesis that dysarthric speakers are particularly susceptible to speech-related fatigue; instead, speech articulation generally appears to be resistant to fatigue induced by an hour of moderate functional exercises.

Keywords

Dysarthria; fatigue; Parkinson's disease; tongue

Introduction

Fatigue is a prominent symptom in a variety of neurologic diseases that often are accompanied by dysarthria. It is associated with disorders characterised by marked weakness of peripheral or central genesis, such as amyotrophic lateral sclerosis (ALS) (Krupp & Pollina, 1996; Sharma et al., 1995), myasthenia gravis (Cantor, 2010) and post-polio syndrome (Stein, Dambrosia, & Dalakas, 1995). Even in the absence of substantial weakness on clinical examination, debilitating fatigue can be a primary symptom in multiple

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Declaration of interest

The authors report no conflicts of interest.

A portion of this study was presented at the Conference on Motor Speech in March 2006 in Austin, TX, and a summary of preliminary results was published in Solomon (2006) based on a presentation at the University of Wisconsin-Madison Medical School Swallowing Conference: *New Frontiers in Dysphagia Rehabilitation*.

sclerosis (MS) (Baylor, Yorkston, Bamer, Britton, & Amtmann, 2010; Yusuf & Koski, 2013) and Parkinson's disease (PD) (Abe, Takanashi, & Yanagihara, 2000; Friedman & Abrantes, 2012; Friedman & Friedman, 1993; Lou, Kearns, Oken, Sexton, & Nutt, 2001). As fatigue can affect motivation, physical functioning, and social activities, it can have a devastating impact on the quality of one's life (Friedman & Friedman, 1993; Hartelius et al., 2004; Herlofson & Larsen, 2003).

A recently proposed taxonomy of fatigue advocated distinguishing perceptions of fatigue, involving homeostatic and psychological factors, from performance fatigability, deriving from peripheral and central mechanisms (Kluger, Krupp, & Enoka, 2013; Lou, 2009). The current study assesses the perception of fatigue according to a self-rated visual analog scale, and performance fatigability according to acoustic measures and auditory perceptual judgments of speech production. Lou emphasises that subjective fatigue may not correlate with fatigability (e.g. a patient who experiences a high sense of effort may still produce normal muscle force), thus emphasising the need to assess both. A well-documented phenomenon in PD is an attenuated or inaccurate self-awareness in relation to performance variables (Hammer, Murphy, & Abrams, 2013; Maier et al., 2012; Pietracupa et al., 2013). Thus, it is conceivable that individuals with PD would not reliably report fatigue, yet fatigue has been listed amongst their most disabling symptoms, and that it differs in quality and severity from fatigue experienced before PD onset (Friedman & Friedman, 1993).

Few studies have characterised the impact of self-perceived fatigue on the dysarthrias. Through multiple linear regression analysis, Baylor et al. (2010) found that, in people with MS, fatigue and slurred speech were negatively associated with communicative participation. Solomon and Robin (2005) reported that, in comparison to neurologically normal adults, people with PD reported heightened effort, which corresponds with the perception of fatigue, for general activities as well as for speaking. These examples indicate that both fatigue and dysarthria can affect communication, but do not reveal whether fatigue has a direct effect on speech.

The underlying perception of fatigue reported by those with neurological disorders may contribute to reduced performance of the speech production mechanism. Investigators exploring the connection between pre-existing orofacial muscle fatigue and disordered speech have often examined the tongue because it is arguably the most important articulator. Other speech-articulation muscles are also important and may be susceptible to fatigue, but have been less often studied and appear to be either as or less fatigable as the tongue (Kuehn & Moon, 2000; Miles & Nordstrom, 1995; van Boxtel, Goudswaard, van der Molen, & van den Bosch, 1983).

Typically, endurance tasks are used to indicate fatigability, because endurance is defined by the ability to maintain a task whereas fatigability is the inability to do so (Solomon, 2006). Tongue endurance can be assessed by maintaining a target force or pressure (e.g. 50% of maximum) as long as possible. The Iowa Oral Performance Instrument (IOPI) has been used for this purpose; it involves compressing an air-filled bulb between the antero-dorsal region of the tongue and the hard palate (Adams, Mathisen, Baines, Lazarus, & Callister, 2013; Robin, Goel, Somodi, & Luschei, 1992). Significantly reduced tongue endurance has been

documented in several populations of neurogenic speech disorders, including those associated with PD (Solomon, Robin, & Luschei, 2000), stroke (Thompson, Murdoch, & Stokes, 1995) and traumatic brain injury (Stierwalt, Robin, Solomon, Weiss, & Max, 1995). In these studies, tongue endurance had minimal correlation to measures of articulatory precision (Solomon, Lorell, Robin, Rodnitzky, & Luschei, 1995; Solomon et al., 2000), suggesting that manifestations of tongue fatigability may be different for speech versus non-speech tasks.

Limited research has addressed the potential relationships between physical exertion and speech. Entwistle (2003) demonstrated that overall physical exertion by healthy young adults elicited changes in normal speech that interfered with speech recognition by computer. In terms of swallowing, Kays, Hind, Gangnon, and Robbins (2010) reported reduced tongue strength and endurance measures after young and older normal adults ate a meal for ~10 min. In addition, the oldest participants (~80 y.o.) exhibited frank signs of dysphagia (wet voice, throat clear, cough) during the meal.

In a study designed explicitly to fatigue the muscles of the tongue and examine its effects on speech, Solomon (2000) had neurologically normal young adults perform strenuous tongue exercises until they met a strict fatigue criterion. This exhausting task successfully elicited perceptible speech deterioration and reversal after rest in every participant. Acoustically, changes were noted for certain spectral and temporal characteristics of consonants, and for the second formant of high vowels and diphthongs. These results revealed for the first time that the fatigue-resistant tongue could indeed be fatigued to the point of negatively affecting speech. We are unaware of any studies that implemented fatiguing activity to examine its effects on speech in persons who have neuromuscular disorders. This study was designed to fill that gap. We reasoned that maximal-effort exercises would be unnecessary and infeasible in a disordered population, and that using a functional activity like speech would increase face validity of the results. The tongue's contribution to speech was the primary consideration in the design of the speech stimuli. Similarly, a bite block was used to reduce the tendency of the jaw to assist with tongue movements for speech. Finally, acoustic variables were selected to best represent the specific contributions of the tongue to the speech signal. If perceptual and acoustic measures change systematically after the tongue exercises, then the common contribution of tongue fatigability would be indicated, although fatigability in other speech muscles could not be ruled out.

Classically, the dysarthria associated with PD, termed hypokinetic dysarthria, is characterised by features that can be attributed at least in part to a restricted range of articulatory movement, namely imprecise consonants and, for some talkers, rapid speech rate (Duffy, 2013; McAuliffe, Ward, & Murdoch, 2006a,b; Walsh & Smith, 2012; Weismer, 1984; Weismer, Jeng, Laures, Kent, & Kent, 2001). Formant frequencies, especially F2 transition in diphthongs, would also be affected because of abnormal extent and duration of tongue movements (Tjaden, Richards, Kuo, Wilding, & Sussman, 2013; Weismer, 1984; Weismer et al., 2001). Temporal characteristics of speech that may also be affected include duration of articulatory obstruction or constriction, or voice onset time (VOT) (Weismer, 1984). Taken together, the dysarthria and fatigue literatures suggest that physically exerting

the tongue in talkers with PD might be expected to worsen the range of tongue motion, affecting speech articulation and speech rate.

Fatigue and fatigability in PD reportedly is associated with physical exertion (van Hilten et al., 1993), but peripheral mechanisms are not necessarily identified (Stegemöller, Allen, Simuni, & MacKinnon, 2010). Instead, the neurophysiological nature of fatigue as reported by people with PD appears to be centrally mediated (Zwarts, Bleijenberg, & van Engelen, 2008). The primary lesion in PD is an extensive loss of dopaminergic cells in the substantia nigra pars compacta. This nucleus normally transmits both inhibitory and excitatory signals to the striatum and then globus pallidus, which in turn inhibits the motor thalamus. This modulates excitatory input to the motor cortex. In PD, the ultimate effect is reduced excitation to motor cortex and consequent reduced excitation to the lower motor neurons (Alexander, Crutcher, & DeLong, 1990). A model of “sense of effort” posits a corollary discharge of the descending motor drive to the lower motor neuron pool (McCloskey, 1981). In PD, the sense of effort may be impaired by a weak efference copy accompanying diminished neural transmission (Rickards & Cody, 1997). To produce the desired movements, a stronger descending signal is required, thus heightening the sense of effort. Indeed, a substantial increase in effort (and a “recalibration” of the same) is a key component of a successful behavioural intensive voice treatment for PD (Ramig et al., 2001).

The present study employed submaximal-effort exercises involving rapid syllable repetitions for 1 h in an attempt to induce acute tongue fatigue in persons with PD and in neurologically normal age-matched adults. Perceptual and acoustic measures of speech were expected to demonstrate that speech affected by a neurological disorder is more susceptible to the effects of physical exertion by the speech articulators. The predictions were that participants with PD would report greater increases in speech-related fatigue and produce greater reductions in speech precision after speech-like exercises than the neurologically normal control participants. To detect potentially subtle differences and to optimise reliability and validity of perceptual ratings, a within-subject paired-comparison procedure was used (Kreiman & Gerratt, 1998). Expected results for the acoustic measures included increased durational aspects of speech, lower intensity, lower formant frequencies, reduced formant-transition slopes, and lower mean and more positively skewed consonantal spectral energy in the PD groups after the speech-like exercises. These findings would support the conclusion that activity-induced tongue fatigue disproportionately impacts speech in this disordered population.

Methods

Experimental study

Participants—All participants provided written informed consent for this study, which was approved by the former Walter Reed Army Medical Center (WRAMC) Institutional Review Board (protocol WU# 02-25007). Twelve adults (10 men and 2 women) with idiopathic PD aged 40–78 years ($M = 66.7$) participated in this study from an initial subject pool of 16 (three consented to participate but failed at least one screening criterion and one withdrew before the final data-collection session). Thirteen neurologically normal adults (7

men and 6 women) aged 47–74 years ($M = 59.9$) participated from an initial subject pool of 16 (three failed to return for data collection). The groups did not differ significantly for age [$t(23) = 1.87, p = 0.08$]. Table 1 lists individual and group mean scores for participants with PD on the examinations and self-rating surveys. Applicable group mean scores for control subjects appear as well.

Each experimental participant had a definitive diagnosis of idiopathic PD verified by the referring neurologist, a self-report of fatigue and a self-report of noticeable changes in speech associated with the disease. They failed a screening for fatigue by scoring within 1 SD of the mean for people with PD (Hagell et al., 2006) on the *Fatigue Severity Scale* (FSS) (Krupp, LaRocca, Muir-Nash, & Steinberg, 1989). Scores for the PD participants ranged from 2.33 to 6.00 ($M = 4.26$). Control participants passed the fatigue screening with FSS scores ranging from 1.00 to 2.22 ($M = 1.60$).

A trained and reliable examiner, also a certified speech-language pathologist (NPS), administered The *Unified Parkinson Disease Rating Scale* (UPDRS) (Fahn, Elton, & Members of the UPDRS Development Committee, 1987) to the participants with PD. The speech item from the *Motor Examination* subtest (Part III, #18) was used to indicate dysarthria severity. Scores range from normal (0) to unintelligible (4) with mid-points between integers allowed. The speech scores of the participants with PD ranged from 0 to 2.5, indicating that speech sounded normal to moderately-to-severely impaired. To avoid potential floor effects resulting from exercise-induced speech deterioration, participants with severe dysarthria were excluded. Participants with normal or only mildly impaired speech were included because they reported noticeable changes of speech since the onset of PD and because the exercise task was expected to worsen speech. Three PD participants (P03, P08 and P16) previously participated in speech therapy, the last of whom had a course of Lee Silverman Voice Treatment® (Ramig et al., 2001) several years prior to this study. None of the participants had been treated surgically for PD.

All participants were screened to rule out history of speech and language disorders (other than those related to PD for participants in the experimental group), other neurologic or orofacial disorders, temporomandibular joint disorders, obtrusive dental appliances, exceptional use of the tongue such as trumpet playing or debating (Robin et al., 1992), hearing impairment (inclusion required pure-tone thresholds ≤ 20 dB HL at 0.5, 1, 2 and 4 kHz in at least one ear) and dementia (inclusion required a score ≥ 24 on the *Mini-Mental State Examination* (MMSE) (Folstein, Folstein, & McHugh, 1975). The *Beck Depression Inventory* (BDI) (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) was administered to assess mood; scores of 11–16 indicate mild depression, and 17 or greater indicates moderate to severe depression. Individuals with PD were tested but were not excluded on this basis because of the high prevalence of depression in PD (Marsh, 2013).

Instrumentation—Speech was recorded in a double-walled sound-attenuating booth with a high-quality head-mounted condenser microphone (AKG C420) coupled with a portable digital recorder (BR-1180) with a sampling rate of 44.1 kHz and a 16-bit quantisation. Sound pressure levels were calibrated by recording a sustained phonation and determining its intensity with a sound pressure level meter (Larson-Davis Sound Level Meter Model

800B, slow response with linear weighting). Praat Software (Amsterdam, The Netherlands) for acoustic analysis of speech (Boersma, 2001) was used to analyse speech data and to prepare audio files for perceptual studies. A fingertip pulse oximeter (Minolta PULSOX-3) monitored oxygen-saturation levels.

Sentence stimuli—The sentence stimuli, listed in Table 2, were modified from a previous study (Solomon, 2000) to allow for examination of multiple productions of high vowels and diphthongs as well as alveolar and postalveolar consonants in VCV environments. Sentence stimuli were designed to induce substantial tongue movement (e.g. elevation and advancement/retraction changes for diphthongs) and precise positioning (e.g. the narrow channel required for fricatives) realised in speech. There were three instances each of the diphthongs /aɪ/ and /ɔɪ/ and the high front vowel /i/ in open syllables, and five intervocalic instances each of /t/, /s/, and /ʃ/ as word onsets. A “challenge” sentence contained multiple coronal–consonant clusters.

Tongue exercises—The speech-like tongue exercises consisted of six sets of rapid repetitions of /tititi.../, /sisisi.../, /ʃiʃiʃi.../, /aɪaɪaɪ.../ and /ɔɪɔɪɔɪ.../, with one randomly selected string of each target syllable per comfortable breath, for 10 min. The number of syllables produced per breath varied depending on each participant’s ability and preference. After each set of tongue exercises, if the fatigue rating indicated tolerance (<80% of maximum; see below), oxygen saturation was 90% and the participant was willing, the exercise task was repeated. All participants met the first two criteria. A subset of participants, after engaging in this task for at least two 10-min blocks, stated that they were not able or willing to continue. To avoid study withdrawal, the investigator provided the option to recite a children’s book loaded with the words “teeny tiny” (Calmenson, 2002) as quickly as possible. Participants were encouraged to return to the syllable repetition task as frequently and for as long as possible. Of the 12 PD participants, 8 were offered the storybook option after 21–54 min of syllable-repetitions (i.e. partway through the third through sixth 10-min sets). Of these eight participants, seven chose the book for a total of 4–19 minutes and one read it for 35 of the 60 min. Only one control subject expressed an unwillingness to continue the syllable repetition task and instead quickly recited the storybook during two exercise sets for 5 min each before returning to the original task.

Fatigue ratings—Participants rated fatigue with a visual analogue scale (VAS, 20-cm undifferentiated lines) labeled “no problem” and “couldn’t be worse” at the endpoints (Peterson et al., 1998). Participants marked the VAS during the last few seconds of each exercise set to indicate self-perceived fatigue from the exercise itself and immediately after reciting the experimental sentences to indicate self-perceived fatigue during speech produced after exercise. The distance from the beginning of the line on the left (“no problem”) to the slash mark was taken as the fatigue rating.

Procedures—Participants attended three separate sessions. Session 1 included informed consent, administration of the UPDRS with the exception of Part III (Motor), FSS, MMSE, BDI and hearing thresholds. Session 2 involved an oral-mechanism examination, the creation and placement of a 3- to 4-mm bite block (3M ESPE dental impression), assessment

of tongue strength (the best of three maximal effort trials) and endurance (maximal duration of pressure sustained at 50% strength), and recordings of sustained /a/, reading passage, spontaneous speech, fast syllable repetitions and the experimental sentences. Tongue strength did not differ between groups [$t(23) = 1.31, p = 0.202$] and was assessed for the purposes of monitoring recovery from exercise and for providing a reference level for an additional non-speech task not reported in this article (constant-effort tongue-to-palate press and hand grip at 50% of maximum tongue or hand strength) (Solomon, Robin, Mitchinson, VanDaele, & Luschei, 1996). Tongue endurance also did not differ between groups [$t(19) = 0.661, p = 0.516$]. Session 3 involved administration of the *Motor Examination* (Part III) of the UPDRS, recording baseline measures and execution of experimental tasks. Participants with PD were instructed to take their antiparkinsonian medications as usual, and data collection was scheduled ~30 min into the drug cycle to capture optimal medication response.

During data collection, the custom-made bite block was placed between the first two upper and lower molars unilaterally. Although pilot data indicated that speaking with a bite block contributes to a perception of decreased speech naturalness (Solomon, Munson, & Makashay, 2004), it was used to stabilise the jaw and prevent compensatory contributions to the task by the mandible. This technique has been used in previous studies of tongue kinematics during speech in an attempt to uncouple lingual and mandibular motions (Palmer & Osborn, 1940; Thompson et al., 1995). Alternate techniques involve mathematical manipulations to subtract mandibular motion (Neto Henriques and van Lieshout, 2013; Westbury, Lindstrom, & McClean, 2002), but constraining jaw movement was better aligned with the present aim of fatiguing the tongue.

Baseline measures included four sets of reading the sentences aloud and then rating overall fatigue with the VAS. Experimental tasks consisted of six sets of: (1) fast syllable repetitions for 10 min, (2) fatigue rating for exercise, (3) oral sentence reading and (4) fatigue rating for sentences. Participants also performed the ~1-min constant-effort task alternated for tongue and hand after each baseline and experimental set; an overview of these results was published previously (Solomon, 2006). Following the six sets of experimental tasks was a final post-exercise stage, with the relevant tasks for this report consisting of: (1) oral sentence reading and (2) fatigue rating for sentences. Study procedures are summarised in Table 3.

Auditory perceptual study: Listeners were nine normal-hearing employees or trainees in the Audiology & Speech Center at WRAMC with graduate training in communication disorders, ranging in age from 23 to 48 years ($M = 33$). They listened to pairs of sentences in random order over headphones in a quiet room. The within-talker sentence pairs consisted of a sentence from the last set of baseline sentences and the same sentence read after the final exercise set. Listeners were blinded to group and exercise condition. They were instructed to choose the sentence in each pair that sounded more precise for consonant and vowel articulation, and the sentence that sounded more natural overall. No-preference ratings were allowed but were discouraged in order to increase statistical power. Listeners rated precision and naturalness on separate days; the task order was randomised.

Acoustic analyses: Detailed descriptions of the acoustic analyses are available in Solomon (2000) and are described briefly here. The first author measured acoustic features of interest on the baseline and sixth-exercise sets of sentences while viewing waveforms and spectrograms in Praat Software. Sentence-level measures included mean fundamental frequency, sound pressure level and articulation rate (syllables/s). Segment-level measures for consonants included stop-closure duration and VOT for /t/, and frication duration for /s/ and /ʃ/. Additional segment-level measures were the first four spectral moments (centre of gravity, *SD*, skewness and kurtosis). Spectral moments were measured after applying pre-emphasis, starting from the /t/ burst with a 10-ms Hamming window and 20 ms after the frication onset of /s/ and /ʃ/ with a 30-ms Hamming window.

Mean F1 and F2 frequencies were measured for the vowel /i/ and mean F1 and F2 frequency slopes were measured for the diphthongs /aɪ/ and /ɔɪ/. The first two formants were taken near the centre of the /i/ steady-state portion and the formant slope averages were calculated automatically by a script written in Praat (corrected by hand when necessary) for /aɪ/ and /ɔɪ/ transition regions with a change of at least 20 Hz over 20 ms. For the /ɔɪ/ diphthongs, 16 F1-slope values were excluded from analysis because of poor quality of the spectrograms or failure to meet the criterion for slope. The missing data were split equally between PD and control subjects, and 11 were from baseline recordings.

The first and senior authors remeasured a random 10% sampling of the vowel data for reliability. Intraclass correlation coefficients for intrarater reliability were 0.976 and 0.997 for steady-state F1 and F2 measurements, and 0.735 and 0.853 for diphthongal F1 and F2 slopes, respectively. Intraclass correlation coefficients between the two authors were 0.953 and 0.984 for steady-state F1 and F2 measurements, and 0.581 and 0.722 for diphthongal F1 and F2 slopes, respectively.

Statistical analyses: All statistical analyses were conducted using SPSS 19 (IBM Corporation, Armonk, NY).

Fatigue ratings—Before analysing fatigue ratings, a pre-test was conducted to examine whether the allowance of an alternate exercise task systematically affected the scores. PD participants were split into two subgroups: six who performed the syllable-repetition task for at least 90% of the total exercise time (6 min of book reading; P06, P07, P12, P14, P15 and P16), and six who performed the syllable-repetition task <90% of the exercise time (P01, P02, P03, P08, P11 and P13). A repeated-measures analysis of variance (RM-ANOVA) with time (before versus after exercise) as the within-subjects factor and subgroup (10% book versus >10% book) as the group factor revealed no significant differences in fatigue ratings between subgroups. This was true both for fatigue rated during the end of the exercise task, $F(1,10) = 1.168, p = 0.305$, and after sentence productions, $F(1,10) = 0.776, p = 0.399$. Thus, the fatigue ratings were combined for statistical analysis.

RM-ANOVAs analysed fatigue ratings with group (PD and control) as the between-subjects factor and time point as the within-subject factor. Exercise-fatigue ratings had six time points (one for each exercise set) and sentence-fatigue ratings had seven (baseline and six exercise sets). One PD and one control subject failed to rate fatigue after the second and

fourth sets of sentences, respectively. Estimates for these two missing values were calculated as the means of the surrounding ratings. The within-subject effect of rating-over-time failed sphericity so Greenhouse–Geisser corrected significance values were used. A Bonferroni correction adjusted the alpha value to 0.025 for the separate analyses of fatigue rated for exercise and sentence tasks.

Auditory perceptual ratings—A pre-test was conducted to determine whether the alternate exercise task affected auditory perceptual ratings of speech. A 2×2 chi-squared analysis (before and after exercise, two subgroups as described under Fatigue ratings) confirmed that ratings of speech naturalness ($\chi^2 = 1.83$, $p = 0.400$) and precision ($\chi^2 = 1.29$, $p = 0.524$) did not differ statistically between PD participants who did and did not resort to the book-reading exercise task > 10% of the time. Therefore, for the combined group of PD participants and for the control participants, pairs of sentences from before and after 60 min of tongue exercises were compared with the Wilcoxon signed-rank test. Differences were considered significant at $\alpha = 0.025$ (2-tailed) after Bonferroni correction.

Acoustics—Inferential statistical analyses of acoustics involved RM-ANOVA with exercise (before and after) as the main within-subjects factor, and group (PD and control) as the between-subjects factor. Partitions of /t/ (stop-closure and VOT) were included as a within-subjects factor in one analysis, and frication duration (/s/ and /ʃ/) in another; Bonferroni correction adjusted the alpha value to 0.025. Mathematical transformation to normalise the scales of spectral moments entailed taking the n^{th} root of the values, where $n = 1-4$, after shifting data points of even moments to positive values by a constant. RM-ANOVA for spectral moment analysis included exercise, moment, and phone (/t/, /s/, /ʃ/). The within-subject effect of moment failed sphericity, so interpretation of that effect used Greenhouse–Geisser corrected significance values. For vowel and diphthongal data, the RM-ANOVA models included the first two steady-state formants of /i/ and the first two formant slopes of the diphthongs, necessitating a Bonferroni correction of the alpha value to 0.025. *Post hoc* RM-ANOVA tests were conducted as indicated.

Results

Fatigue ratings

Figure 1 illustrates mean (and *SD*) ratings of fatigue over time according to task and group. Participants' fatigue increased significantly over time across the six exercise sets when rated immediately after reading sentences aloud, $F(3.98, 91.60) = 4.26$, $p = 0.003$, but not when rated during the final seconds of each exercise set, $F(2.94, 67.58) = 1.95$, $p = 0.131$. The PD group rated fatigue for sentence production significantly higher than the control group, $F(1, 23) = 10.49$, $p = 0.004$. Fatigue ratings during the syllable repetitions tended to differ between groups but did not meet the criterion for statistical significance, $F(1, 23) = 4.40$, $p = 0.047$.

Auditory perceptual ratings

Figure 2 illustrates the proportion of sentences that listeners rated as more precise and natural by group. Judgments did not differ significantly before versus after tongue exercises,

either for articulatory precision, $Z = -1.13$, $p = 0.258$ or speech naturalness $Z = -1.60$, $p = 0.110$. There were also no significant differences for analyses performed by group (PD precision: $Z = -0.67$, $p = 0.505$, PD naturalness: $Z = -1.10$, $p = 0.271$, control precision: $Z = -0.87$, $p = 0.387$, control naturalness: $Z = -1.60$, $p = 0.109$).

Acoustic results

Summary statistics for mean F_0 , intensity, and articulation rate for sentence productions appear in Table 4. F_0 data are presented separately for male and female speakers because of large expected difference in F_0 between the sexes. Mean F_0 increased significantly by an average of 8Hz after the exercise task, $F(1,23) = 14.44$, $p = 0.001$, $\eta_p^2 = 0.39$, power = 0.95, with no significant main effect for group, $F(1,23) = 2.29$, $p = 0.144$, or interaction between exercise and group, $F(1,23) = 3.24$, $p = 0.085$. There was a statistically significant main effect of sex, $F(1,21) = 95.77$, $p < 0.001$, but no interaction of sex with group, $F(1,21) = 3.28$, $p = 0.085$, or exercise, $F(1,21) = 1.08$, $p = 0.310$, for F_0 . Mean intensity increased significantly by an average of 1 dB after exercise, $F(1,23) = 5.83$, $p = 0.024$, $\eta_p^2 = 0.20$, power = 0.64, with no significant main effect for group, $F(1,23) = 2.87$, $p = 0.104$, or exercise-by-group interaction, $F(1,23) = 0.03$, $p = 0.876$. Articulation rate did not differ significantly with exercise, $F(1,23) = 0.31$, $p = 0.584$, between groups, $F(1,23) = 0.56$, $p = 0.464$, or as an interaction between exercise and group, $F(1,23) = 2.20$, $p = 0.151$.

Summary statistics for durational characteristics and spectral moments of /s/, /ʃ/, and /t/ appear in Tables 5 and 6, respectively. The duration of /t/ closure and VOT did not change significantly after exercise, $F(1,23) = 0.02$, $p = 0.899$, differ significantly between groups, $F(1,23) = 2.95$, $p = 0.099$, or interact significantly for exercise-by-group, $F(1,23) = 0.77$, $p = 0.389$. Frication duration of /s/ and /ʃ/ did not differ significantly with exercise, $F(1,23) = 1.28$, $p = 0.269$, between groups, $F(1,23) = 3.22$, $p = 0.086$, or for their interaction, $F(1,23) = 0.00$, $p = 0.971$. Spectral characteristics of the consonants, as reflected by moments 1–4, did not significantly differ after exercise, $F(1,23) = 0.33$, $p = 0.570$, between groups, $F(1,23) = 1.30$, $p = 0.266$, or for their interaction, $F(1,23) = 0.21$, $p = 0.649$. There was no statistically significant main effect of sex, $F(1,21) = 0.48$, $p = 0.495$, and no interactions between sex and group, $F(1,21) = 0.47$, $p = 0.500$, or exercise, $F(1,21) = 1.36$, $p = 0.257$, for spectral moments.

Mean formant frequencies for /i/ and formant slopes for /aɪ/ and /ɔɪ/ appear in Table 7. F1 and F2 for /i/ did not differ significantly, with Bonferroni correction, after exercise, $F(1,23) = 4.22$, $p = 0.052$, between groups, $F(1,23) = 5.22$, $p = 0.032$, or for the group-by-formant interaction, $F(1,23) = 4.79$, $p = 0.039$. There was a statistically significant main effect of sex, $F(1,21) = 45.11$, $p < 0.001$, and an interaction of sex with formant, $F(1,21) = 33.86$, $p < 0.001$, but not with group, $F(1,21) = 0.17$, $p = 0.681$, or exercise, $F(1,21) = 0.32$, $p = 0.580$, for /i/ formants. The control group tended to have higher F2 values than the PD group. F1 and F2 formant slopes for /aɪ/ and /ɔɪ/ did not differ significantly after exercise, $F(1,23) = 0.19$, $p = 0.668$, or between groups, $F(1,23) = 0.25$, $p = 0.623$. Group-by-formant, $F(1,23) = 12.16$, $p = 0.002$, and formant-by-diphthong, $F(1,23) = 12.49$, $p = 0.002$, interactions were significant. F1 slope was steeper for control than PD participants for /aɪ/, $F(1,23) = 9.09$, $p = 0.006$, and /ɔɪ/, $F(1,23) = 12.54$, $p = 0.002$. F2 slope was significantly steeper for control

than PD participants for /aɪ/, $F(1,23) = 7.30$, $p = 0.013$, but not /ɔɪ/, $F(1,23) = 0.73$, $p = 0.403$. There was no statistically significant main effect of sex, $F(1,21) = 0.02$, $p = 0.903$, or interaction of sex with group, $F(1,21) = 0.05$, $p = 0.824$, or exercise, $F(1,21) = 0.12$, $p = 0.733$, for formant slopes.

Discussion

To test a common assumption that the speech of persons with dysarthria is more susceptible to fatigue than normal, this study attempted to induce tongue fatigue with speech-like tongue exercises in speakers with PD and neurologically normal adults. Prolonged submaximal-effort exercises, consisting of rapid repetitions of syllables and rapid reading from a simple text, were hypothesised to affect tongue function for the participants who have PD but not for the neurologically normal participants. The results of this study did not support this hypothesis. After an hour of speech-related exercises, sentences read by both groups of participants did not sound significantly less natural or less precise to trained listeners. Individual differences were noted from talkers in both groups, but the changes across individuals were not systematic.

The choice to use a speech-like task to induce tongue fatigue was based largely on the desire to demonstrate construct validity and secondarily on ethical concerns to avoid exhausting persons with a neurological disorder. Previous research (Solomon, 2000) found significant effects on speech, both perceptually and acoustically, from an intensive exercise task that induced tongue fatigability in neurologically normal adults. The lack of such effects in the present study suggests that the speech-like submaximal tongue exercises were not fatiguing enough in either group to significantly change speech in a way that was perceptually salient or acoustically measurable.

Speech-related muscles are considered distinctive among motor systems as being largely fatigue resistant (Kent, 2004). The present study is consistent with this information, but a previous study indicated that tongue endurance was reduced by eating a single ~10-min meal in both young and older healthy adults (Kays et al., 2010). This surprising result is hard to reconcile with the current results, but suggests that the tongue is more susceptible to fatigability from eating than from talking, or that measures of tongue endurance are more sensitive to change than are perceptual and acoustic measures of speech. The latter reason is more likely, given that endurance testing requires maximal effort to perform whereas the strength required for speech is submaximal.

Although the PD group's self-ratings of fatigue for the sentence-reading task were significantly higher than the control group's ratings overall, both groups indicated that fatigue increased significantly over time. Given evidence that persons with PD report greater fatigue than normal (Abe et al., 2000; Friedman & Abrantes, 2012; Friedman & Friedman, 1993; Lou et al., 2001), it is possible that the PD participants were chronically fatigued at baseline. If so, then any further fatigue or fatigability caused by the exercises may not have affected speech to the extent that the change was detectable by a listener.

It is also possible that disease-related fatigue and fatigability may have been masked to some extent because testing was conducted while participants were optimally medicated. Any such effect was likely nominal, as previous research has demonstrated that levodopa does not affect perceived exertion and effort significantly during an exercise task (Le Witt et al., 1994). In addition, medications appear to have less of an effect on brain activation during speech than for hand movements in PD (Maillet et al., 2012) and levodopa affects speech inconsistently within and across talkers (De Letter et al., 2010; Goberman & Coelho, 2002).

Despite the lack of auditory perceptual differences, the prolonged tongue exercise task affected certain acoustic aspects of voice. Mean sentence F_0 and intensity were slightly but statistically significantly higher after exercise for both groups. Vocal fatigue might contribute to these changes, as prolonged loud talking generally results in increased F_0 and SPL (Laukkanen, Ilomäki, Leppänen, & Vilkman, 2008; Solomon, 2008). Anecdotally, the trained listeners sometimes indicated that intonation related to expressiveness was the most obvious difference in stimulus pairs presented for perceptual comparisons. Upon further inspection, the investigators determined that most of the expressively read sentences occurred after exercise and that voice quality (i.e. strain, breathiness and roughness) did not deteriorate notably. These results and observations suggest that the speech-like exercises performed by both groups may have provided a somewhat energising rather than fatiguing effect that was revealed in the voice. It is possible that speakers compensated for the internal sensation of fatigue after the speech-like exercises by exerting more energy during the sentence tasks, which manifested in increased pitch, loudness, and intonation variability.

No acoustic variables related to speech articulation or rate varied systematically after the tongue exercises, but there were a few acoustic differences between the participant groups regardless of exercise. $F1$ slope for /aɪ/ and /ɔɪ/ and $F2$ slope for /aɪ/ were significantly steeper for control than PD participants. A possible explanation is that talkers with PD may produce diphthongs with smaller changes in tongue elevation and fronting than controls. This finding is consistent with previous literature that reported reduced acoustic contrastivity in speakers with hypokinetic dysarthria compared to normal speakers (Rosen, Kent, Delaney, & Duffy, 2006; Weismer, 1984) including reduced formant slopes (Forrest, Weismer, & Turner, 1989; Tjaden & Wilding, 2004).

Bite blocks may have contributed to acoustic differences between the participant groups. In this study, bite blocks were used with the intent of stabilising the jaw and isolating the tongue, but they did not prevent talkers from opening their mouths. Increased jaw lowering would raise $F1$ onset values and increase $F1$ slopes, potentially increasing the amount of tongue backing which would lower the $F2$ onset values and increase $F2$ slopes. Given these acoustic predictions, it is possible that control subjects opened their mouths wider than PD subjects during sentence productions. Alternately, they could have altered the oral space more within the constraints of the bite block by flattening the tongue, widening the pharynx or separating the lips to achieve the desired acoustic target. In either case, it appears that the neurologically normal talkers used greater flexibility in their speech motor control systems during production of diphthongs in sentences than the talkers with PD, whether they were rested or exercised. This is consistent with the clinical signs of akinesia and hypokinesia in PD.

Another potential confound of using a bite block may have been an overall contribution to the perception of fatigue because the jaw-closing muscles are activated to hold the block in place (Solomon & Munson, 2004). This additional muscular effort would not be expected to affect speech articulation and could partially explain why the self-perception of fatigue increased over the course of the exercise task whereas the auditory perceptual and acoustic characteristics of the speech did not correspond.

There is evidence that people with PD have abnormal auditory feedback for vocal loudness (Ho, Bradshaw, & Iansek, 2000; Liu, Wang, Metman, & Larson, 2012). Likewise, it is plausible that they may also have abnormal auditory feedback for articulatory precision. Rickards and Cody (1997) speculated that the efference copy of motor output is reduced in persons with PD, and when that copy is compared to sensory feedback, the mismatch leads to a reduction in subsequent motor output. If individuals with PD do not notice the imprecision of their speech, they may continue to speak imprecisely. McAuliffe and colleagues demonstrated that people with PD do not apply an adequate amount of tongue pressure for precise articulation (McAuliffe et al., 2006a) despite having normal tongue strength for non-speech tasks (McAuliffe, Ward, Murdoch, & Farrell, 2005). Perhaps like achieving adequate vocal loudness, persons with PD also have difficulty maintaining adequate tongue pressure while producing consonants.

Although the perceptual ratings of speech for the PD group as a whole did not differ significantly before versus after exercise, there were large individual differences. It is interesting to note how these external ratings of speech compare to talkers' internal perception of fatigue. The speech of two participants with PD (P6 and P16) was judged to be decidedly less precise after than before exercise. P6's self-perceived fatigue during sentence reading was the lowest of all PD participants, and her ratings did not increase with exercise; this may indicate a lack of self-awareness of fatigue given that her speech was so noticeably affected. P16, however, had a nearly perfect monotonic increase in his sentence-production fatigue ratings from baseline through the final exercise set, matching the deterioration in his speech as perceived by the listeners. Participant P3, on the other hand, continuously increased his sentence fatigue ratings for all but one exercise set, yet his speech was not judged to be less precise after exercise. These observations are consistent with Lou's (2009) assertion that fatigue and fatigability are not necessarily correlated.

Interpretation of the data may have been complicated by potential confusion between fatigue and boredom. It appears that the exercise task was so tedious (Solomon, 2006) that a number of PD participants and one control participant requested a respite from rapid syllable repetitions after several sets. To avoid attrition, the experimenter reluctantly provided a storybook loaded with alveolar consonants, asked them to recite it as quickly as possible, and encouraged them to return to the syllable-repetition task as often as possible. Additionally, five PD participants and two control participants requested and were granted breaks. Clearly, the exercise task designed for this study was difficult to sustain and enforce, and appeared to be less well tolerated by the participants with PD than control participants. These observations support existing literature regarding a greater likelihood of mental fatigue or reduced motivation in PD than in neurologically normal adults (Lou, 2009; Lou et

al., 2001; Sáez-Francàs, Hernández-Vara, Corominas Roso, Alegre Martín, & Casas Brugué, 2013).

Limitations

This study was limited in some ways by the participant pool, the exercise task, and the perceptual rating scale. Most of the PD participants had mild dysarthria and did not demonstrate tongue fatigue as indicated with an endurance task. Although tongue endurance has been shown to be lower than normal in a group of adults with PD (Solomon et al., 2000) and the majority of people with PD report fatigue (Friedman & Abrantes, 2012), the differences may not be evident on an individual basis. Another limitation regarding participant groups was the unequal representation of women and men. The exercise task was perhaps too simplistic and repetitive. The same syllables were repeated *ad infinitum*, so any motor planning after the first repetition was minimal and talkers may have developed compensatory strategies. If the participants used an articulatory loop, the same production pattern would be used until the next syllable was chosen. Talkers were also allowed an alternative task for a portion of the exercise phase that may have had a different effect on performance fatigability. Finally, a different type of perceptual rating scale may have yielded different results, although the paired-comparison method was selected because it is most likely to reveal subtle differences between productions (Kreiman & Gerratt, 1998). Furthermore, asking listeners to focus on breathing or phonatory aspects of speech rather than articulatory precision might have led to differences. We expected but did not find such changes to be reflected by the naturalness ratings.

Future research

For future research to elucidate the role of fatigue on functional activities such as speech or swallowing, it should carefully consider the complex nature of fatigue (Elbers, van Wegen, Verhoef, & Kwakkel, 2014; Lou, 2009; Thorpy & Adler, 2005; van Dijk et al., 2013). Self-perceived fatigue, which could reflect increased sense of physical or mental effort, boredom or sleepiness, may cause people with PD to underestimate their abilities to perform tasks, curtailing their participation in such tasks. This truncated participation may reinforce their belief that they are too fatigued to continue, but if they overcame their reluctance, they may be able to complete tasks as well as their neurologically normal counterparts. In addition, the abnormal sensory feedback experienced by patients with PD may reduce their physical output to suboptimal levels despite their belief that they are performing adequately. Abnormal perception of fatigue and abnormal sensory feedback in patients with PD may be related, and is a worthy topic for future investigations.

A more complex speech task that better represents real-world utterances might yield interesting results in new studies on the effect of mental or cognitive fatigue on speech. Longer text sources would require participants to continually plan and execute each new utterance. The text would ideally have multiple polysyllabic words per sentence, but be within the participants' reading level. It would also be more realistic, yet challenging, as readers would be processing the text on multiple linguistic levels including morphosyntactic, semantic and pragmatic, not merely on phonetic and phonological levels.

Measures of tongue pressures and contact patterns during speech tasks (McAuliffe et al., 2006a,b; Searl & Evitts, 2013) is a promising approach for investigating the effects of fatigue on speech production. Examining how fatigue affects consonant closure pressure and constriction area in talkers with PD might explain unexpected findings from acoustic and perceptual measures. Finally, testing more severely dysarthric individuals or testing participants in the off-medication cycle might also reveal greater susceptibility to speech changes with fatigue.

Conclusion

The results of this study were expected to support the hypothesis that a prolonged rapid speech-like task would exacerbate dysarthria in subjects with PD, but not lead to deterioration of speech in normal talkers. Although participants in both groups reported increasing fatigue, perceptual analyses revealed no significant differences between speech produced before and after exercise. This was true for perceptions of both articulatory precision and overall naturalness. Acoustic analyses also failed to reveal many significant differences for group or exercise for segmental analyses of speech. The acoustic results that were significant are inconsistent with predictions of speech deterioration with exercise. Rather, they could reveal increased phonatory or respiratory effort, or suggest an energising effect of the exercises on speech in both subject groups despite self-perceived fatigue. These findings are consistent with the notion that speech articulation is resistant to activity-induced fatigue, and that speaking alone does not easily lead to fatigue.

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Figure 1.

Visual analogue scale ratings of self-perceived fatigue by group immediately after reading each set of sentences aloud (left) and at the end of each set of speech-like tongue exercises (right). Error bars equal 1 *SD*.

Figure 2. Listener preferences for precision and naturalness when comparing sentences produced before and after 60 min of speech-like exercises by PD and control participants.

Table 1

Participants' ages and test scores by group.

Subject	Age	MMSE	BDI	FSS	Speech	UP-III	UP-Total	H&Y
PD								
P01	64	30	17	4.33	1	32	92	2.5
P02	75	28	9	4.78	1	33.5	115	3
P03	73	30	8	4.56	1	41	119	2
P06	64	30	16	3.67	0	17.5	46	2
P07	59	28	20	5.22	0.5	25	92	2.5
P08	71	28	9	5.11	1	26.5	107	3
P11	68	30	17	4.11	1	34	94	3
P12	40	27	11	6.00	1.5	37.5	134	3
P13	72	27	8	3.33	1	32	100	2.5
P14	78	25	10	4.33	2.5	38.5	141.5	3
P15	68	29	4	3.33	1	20.5	57	2.5
P16	68	24	15	2.33	1.5	26.5	89	2
M	66.7	28.0	12.0	4.26	1.08	30.38	98.9	2.58
SD	9.9	2.0	4.8	0.99	0.60	7.26	27.9	0.42
Control								
M	59.9	29.4	1.8	1.60				
SD	8.1	0.8	3.5	0.44				

MMSE, Mini-Mental State Examination; BDI, Beck Depression Inventory; FSS, Fatigue Severity Scale; Speech, Score on question 18, Part III, on the Unified Parkinson Disease Rating Scale (UPDRS); UP-III, Part III of the UPDRS scored immediately preceding the experimental task (on-med); UP-Total, total of parts I-IV on the UPDRS; H&Y, Hoehn & Yahr score on the UPDRS while PD participants were in an on-medication phase.

Table 2

Sentence stimuli with diphthong and vowel stimuli overlined and consonant stimuli underlined.

They fly [̄] up [̄] high [̄] in the sky [̄] again.
Let the boy [̄] enjoy [̄] a toy [̄] again.
The two [̄] silly [̄] tēachers [̄] enjoy [̄] tēasing [̄] the seal.
You sh [̄] ould really sh [̄] ow Tina [̄] how to sh [̄] ine the sh [̄] oes.
I s [̄] aid the sh [̄] ellfish would be t [̄] oo s [̄] alty by S [̄] aturday.
Mr. Fox wished six students would straighten and dust their desks.

Table 3

Study procedures.

A. Session 1	
1.	Screening and baseline assessments
2.	Practice productions of sentence stimuli (Table 2)
B. Session 2	
1.	Create and place custom bite block
2.	Maximum tongue/hand pressure ($P_{\max}$, best of three trials)
3.	Constant effort starting at 50% $P_{\max}$ (three trials, alternate tongue/hand)
4.	Maximum endurance at 50% $P_{\max}$ (tongue/hand)
C. Session 3	
1.	Pre-exercise trials (repeat for total of four sets)
a.	Sentences
b.	Fatigue VAS rating (note O_2 saturation)
c.	Constant effort trials (one set: tongue/hand)
d.	Fatigue VAS rating after each constant effort trial
2.	Exercise Phase 1
a.	10-min speech-like exercises
b.	Fatigue VAS rating
c.	Sentences
d.	Fatigue VAS rating
e.	Constant effort trials (one set)
f.	Fatigue VAS rating for each (note O_2 saturation)
3.	Exercise Phases 2–6
a.	Repeat C.2.
4.	Recovery Phase
a.	Maximum tongue strength (30 s intervals until 90% $P_{\max}$)
5.	Post-recovery Phase (data not included in this article)

Table 4

Mean (and SD) fundamental frequency (F_0 , in Hz, by sex), intensity (dB SPL), and articulation rate (syllables/s) for sentences produced by PD and control participants before and after 60 min of speech-like exercises.

Variable	PD		Control	
	Sex	Before	Sex	After
F_0	M($n=10$)	109.4 (17.6)	M ($n=7$)	115.2 (13.3)
	F($n=2$)	195.8 (42.5)	F ($n=6$)	173.6 (16.5)
Intensity		85.8 (4.7)		82.6 (4.8)
Rate		4.42 (0.68)		4.14 (0.60)

Table 5

Mean (and *SD*) durations (in ms) for lingua-alveolar consonants produced within sentences by PD and control participants before and after 60 min of speech-like exercises. Variables were frication duration for /s/ and /ʃ/, and closure duration and voice onset time (VOT) for /t/.

Duration	PD		Control	
	Before	After	Before	After
/s/ frication	129.1 (27.0)	126.0 (28.4)	142.0 (18.2)	138.8 (17.4)
/ʃ/ frication	124.3 (19.4)	121.3 (25.0)	138.4 (17.3)	135.1 (15.7)
/t/ closure	75.3 (18.2)	79.1 (22.9)	80.2 (14.5)	80.3 (15.7)
/t/ VOT	51.4 (12.6)	50.7 (12.4)	65.6 (19.9)	61.3 (12.7)

Table 6

Mean (and SD) values of the first four spectral moments of /t/, /s/ and /ʃ/ produced by participants in the PD and control groups before and after exercises.

Moment	Phoneme	PD		Control	
		Before	After	Before	After
M1 (kHz)	/t/	9.28 (1.36)	9.43 (1.49)	8.62 (1.06)	8.77 (1.29)
	/s/	9.06 (1.38)	8.81 (1.36)	8.83 (1.12)	9.20 (1.13)
	/ʃ/	7.44 (1.33)	7.58 (1.40)	7.22 (1.05)	7.09 (1.17)
M2 (kHz)	/t/	3.41 (0.56)	3.51 (0.50)	3.55 (0.68)	3.33 (0.75)
	/s/	3.24 (0.68)	3.15 (0.54)	2.99 (0.49)	2.84 (0.45)
	/ʃ/	3.56 (0.73)	3.44 (0.58)	3.37 (0.62)	3.31 (0.60)
M3	/t/	0.09 (0.54)	-0.05 (0.56)	0.31 (0.48)	0.34 (0.54)
	/s/	0.24 (0.49)	0.25 (0.55)	0.46 (0.62)	0.30 (0.52)
	/ʃ/	0.49 (0.56)	0.33 (0.62)	0.49 (0.45)	0.60 (0.52)
M4	/t/	0.37 (1.00)	0.10 (0.93)	-0.04 (1.35)	0.23 (1.32)
	/s/	0.20 (1.19)	0.33 (1.21)	0.36 (1.44)	0.40 (0.96)
	/ʃ/	0.28 (1.79)	0.14 (1.15)	0.04 (1.01)	0.20 (1.14)

Table 7

Mean (and SD) values of F1, F2 frequency (kHz) for /i/ and F1, F2 slope (Hz/ms) for /aɪ/ and /ɔɪ/ for PD and control groups before and after exercises.

Phoneme	Parameter	Sex	PD		Control	
			Before	After	Before	After
/i/	F1	M	0.286 (0.025)	0.286 (0.033)	0.282 (0.035)	0.286 (0.038)
		F	0.311 (0.023)	0.303 (0.027)	0.335 (0.047)	0.345 (0.052)
	F2	M	2.086 (0.182)	2.121 (0.164)	2.219 (0.185)	2.223 (0.159)
		F	2.565 (0.133)	2.616 (0.037)	2.599 (0.112)	2.626 (0.132)
/aɪ/	F1 slope		-2.429 (1.246)	-2.393 (1.737)	-4.029 (1.994)	-4.120 (2.774)
			5.768 (2.606)	5.117 (1.423)	7.099 (2.544)	6.920 (1.965)
/ɔɪ/	F1 slope		-1.637 (0.691)	-1.660 (0.866)	-3.038 (1.809)	-2.354 (0.902)
			8.774 (2.768)	8.018 (2.614)	8.878 (2.585)	9.040 (2.271)