Parkinson's disease and the effect of lexical factors on vowel articulation

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Abstract: Lexical factors (i.e., word frequency and phonological neighborhood density) influence speech perception and production. It is unknown if these factors are affected by Parkinson's disease (PD). Ten men with PD and ten healthy men read CVC words (varying orthogonally for word frequency and density) aloud while audio recorded. Acoustic analysis was performed on duration and Bark-scaled F1-F2 values of the vowels contained in the words. Vowel space was larger for low-frequency words from dense neighborhoods than from sparse ones for both groups. However, the participants with PD did not show an effect of density on dispersion for high-frequency words.

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1. Introduction

The size of the F1-by-F2 vowel space is an important determinant of speech intelligibility. Talkers with smaller-sized vowel spaces are less intelligible than those with larger vowel spaces.^{1,2} The size of the F1-by-F2 vowel space is reduced in persons with Parkinson's disease (PD) relative to healthy adults.^{3,4} Consequently, there is a smaller acoustic distance between vowels. This presumably makes it more difficult for listeners to discriminate differences among vowels. Vowel space is particularly sensitive in predicting speech intelligibility in persons with PD,⁴ and knowledge of factors that contribute to vowel space would be important to understand.

In neurologically healthy talkers, within-talker vowel production is not only affected by task-related variables (e.g., articulation rate and presence of background noise) but also by lexical factors such as phonological neighborhood density and word frequency. Neighborhood density is defined as the number of words that differ by one phoneme (e.g., *kin*'s neighbors include *in*, *skin*, *can*, and *kiss*). Infrequently used words from dense neighborhoods are more difficult to identify than high-frequency low-density words.⁵ In both younger and older adults, less frequently used words from dense neighborhoods are produced with more expanded vowel space than frequently used words from sparse neighborhoods.⁶⁻⁹ Wright⁶ maintained that one possible reason for this expansion of vowel space is that talkers are accommodating listeners by making vowels from these lexically difficult words more distinct, thus partially countering the intelligibility decrement that the "hard" words offer.

There is a reason to suspect an interaction of PD with lexical factors. PD is caused by a loss of dopaminergic neurons within the basal ganglia. Ullmann¹⁰ proposed that the basal ganglia are involved in the selection and organization of phonemes for word production, and the basal ganglia have been implicated in phonological processing in neuroimaging and neuroelectrophysiological studies of awake-healthy humans.¹¹⁻¹³

The identification of acoustic variables predictive of poor intelligibility in persons with PD has not yielded satisfactory results.^{4,14} The purpose of this preliminary investigation was to examine the effect of word frequency and neighborhood density on vowel production in persons with PD. A finding that persons with PD do not modify their vowel production in response to word frequency and neighborhood density would motivate future studies of linguistic influences on speech production and its relations to intelligibility.

Table 1. Stimulus words used.

Vowel	High frequency/ high density	High frequency/ low density	Low frequency/ high density	Low frequency/ low density
ɑ	got	dock	dot	mop
ʊ	pot	top	cot	cop
æ	sad	sang	fad	sag
ɛ	get	death	dept	deaf
eɪ	game	gain	dame	babe
i	beat	beach	beak	leach
ou	note	wrote	moat	rope
u	moon	room	womb	tune

2. Methods

Ten men diagnosed with idiopathic PD participated and were of an average age of 73 years ($SD=9.5$ years). A group of ten healthy men, with an average age of 72 years ($SD=7.7$ years), served as healthy controls (HCs). Data from five of these HC participants had been analyzed and reported previously.⁹ Of the participants with PD, four had Hoehn-Yahr¹⁵ scores of 3 and six had scores of 4. All participants with PD were judged by the first author (a certified speech-language pathologist) to have dysarthria. Participants with PD scored 26 or higher on the Mini-Mental-Scale-Examination. Audio recording of persons with PD was done when they reported they were “on” state, 1–2 h after taking their medications. All participants were native American-English talkers.

In order to shorten the elicitation session to minimize possible fatigue, the stimuli were 32 CVC words with monophthongal vowels (/i/, /a/, /eɪ/, /ɛ/, /æ/, /ou/, and /u/) from a subset of the 80 words used by Munson and Solomon.⁷ Four lists were constructed with high- and low-frequency words coming from phonological neighborhoods of high and low densities. The lists were constructed by conducting a median split for the raw frequency and frequency-weighted neighborhood density values for the CVC words in the Hoosier-Mental-Lexicon¹⁶ and constructing phonemically matched quadruplets of words containing the same vowel.¹⁷ The average occurrence of the high-frequency words was 182, while the average for the low-frequency words was 7. This difference was significant in an ANOVA ($F[1,28]=11.4$, $p=0.002$). The average frequency-weighted neighborhood density was 188.4 for the high-density words and 32.6 for the low-density words. This was significant, $F[1,28]=49.5$, $p<0.001$. Though the high- and low-density lists were not designed to contrast in raw neighborhood density, the two lists did differ marginally in this variable, $F[1,28]=3.2$, $p=0.084$. The high-density words had on average 3 more neighbors than the low-density ones. See Table 1 for the words used.

Participants read the words aloud from cards in quasirandom order. Each word was read three times, for a total of 96 productions per participant. Each participant was seated and wore a head-mounted condenser microphone (AKG, 420) interfaced with a digital-CD recorder (Marantz, DRR300). The acoustic data were recorded at 44.1 kHz sampling frequency with 16 bit quantization.

Vowel segments were determined from both the waveform and spectrogram displays with linear predictive coding superimposed over the spectrogram display using PRAAT software.¹⁸ From the marked segments, vowel duration and Bark-scaled F1 and F2 values¹⁸ were extracted. For each vowel, mean vowel duration, mean F1, mean F2, and mean vowel-space dispersion were calculated. The mean F1 and F2 values collapsed for all vowels provided an average-centroid value within the vowel space. The calculation of vowel dispersion was determined by taking the average Euclidean distance of the individual vowels from the center of the vowel space, defined operationally as the average F1 and F2 for the entire set of vowels. A

Table 2. Means and standard error of the mean (in parenthesis), in milliseconds, for the HC and the PD groups.

	High frequency/ high density	High frequency/ low density	Low frequency/ high density	Low frequency/ low density
HC	219.62 (9.29)	210.69 (8.23)	211.09 (10.97)	288.05 (7.51)
PD	246.43 (23.53)	240.18 (22.62)	233.57 (16.40)	230.82 (20.46)

three-factor mixed-model ANOVA, with participant group as the between factor and word frequency and density as the within factors, was used to test vowel duration and dispersion.

3. Results

Vowel duration for the HC and PD groups are shown in Table 2. On average, vowel duration was longer for the PD group, but the ANOVA showed no main effect for group due most likely to the large variability within the PD group. There was a significant frequency by group interaction [$F(1, 18) = 6.288$, $p = .022$, $\eta^2 = 0.259$], showing that vowels in high-frequency words were longer for the PD group only.

Vowel dispersion for high- and low-frequency and high- and low-density words are shown in Fig. 1. As can be seen, average dispersion was larger in the HC group for all words. The ANOVA showed a significant main effect for group [$F(1, 18) = 11.93$, $p = .003$, $\eta^2 = 0.40$]. There were also a significant effect of density ($F(1, 18) = 13.95$, $p = 0.002$, $\eta^2 = 0.44$), a significant frequency by density interaction ($F(1, 18) = 12.68$, $p = 0.002$, $\eta^2 = 0.41$), and a significant group by frequency by density interaction [$F(1, 18) = 5.843$, $p = 0.026$, $\eta^2 = 0.25$]. Follow-up testing with Bonferroni-corrected independent sample t-tests revealed significant group differences in dispersion for all four stimulus types. The three-way interaction can be seen by comparing the bar heights in Fig. 1. Bonferroni-corrected t-tests showed that the HC talkers produced more-dispersed vowels in high-density words than low-density words regardless of whether they were high or low in frequency [$t(9) = 3.2$ and 2.9 and $p = 0.011$ and 0.018 , respec-

Fig. 1. Mean F1/F2 vowel dispersion and standard error of the mean (error bars) in Bark, for high-frequency high-density, high-frequency low-density, low-frequency high-density, and low-frequency low-density words for the HC and PD groups.

tively]. There were no effects of word frequency. For the PD talkers, there was an effect of density for the low-frequency words only [$t(9)=3.0$, $p=0.015$]. Moreover, the high-frequency low-density words were less dispersed than the low-frequency low-density words [$t(9)=3.24$, $p=0.01$].

Finally, a set of regression analyses examined whether the influence of group, frequency, and density on vowel-space dispersion was an artifact of vowel duration, as previous research has shown these variables to be correlated.¹⁹ This was accomplished by conducting a regression predicting average dispersion from average duration. Eighty data points were used in this regression, representing the four data points for all 20 participants. The regression was significant, but with only 6% of the variance in dispersion being attributable to duration. Furthermore, this relation was in the opposite-than-predicted direction, owing largely to the fact that the individuals with PD produced both longer durations and less-expanded vowel spaces.

4. Discussion

These findings suggest that the effect of PD on speech produces a more complex interaction of vowel production than has previously been described. Vowel-space dispersion was contracted in the PD group for this current study, which is consistent with numerous other studies of the speech of individuals with PD (e.g., Refs. 3, 4, and 14). Vowel-space dispersion was not an artifact of duration-dependent undershoot, as demonstrated by the inverse relation between duration and dispersion in the PD group.

Even though vowel dispersion in the PD group was contracted for all words, they did show some of the same lexical effects that had been demonstrated previously in the speech of individuals without speech, language, or hearing disorders. The PD group, for example, showed the expected effect of density on vowel-space dispersion for low-frequency words, though not for high-frequency words. That the effect of density would be limited to low-frequency words is consistent with Wright's⁶ initial speculation that these effects derived from tacit attempts to enhance perceptibility of words, as low-frequency words are predicted overall to be less intelligible than high-frequency ones. It is also consistent with the pattern found for a larger group of healthy older adults analyzed by Watson and Munson.⁹ The reason that this pattern was not observed in high-frequency words is less clear, but we offer three possible explanations. First, as suggested by Munson,⁸ word-frequency effects appear more vulnerable to task-related influences than those of density and would be less consistent across studies and corpora. Second, a recent study²⁰ showed that persons with PD had impaired recall for high-frequency but not for low-frequency words when compared to healthy age- and gender-matched controls. It is possible that persons with PD are less sensitive to density effects when producing high-frequency words. Third, although all participants with PD were identified as having dysarthria, no determination of speech impairment severity was made, which may have had an effect on density discrimination in high-frequency words. However, further study is required to determine the reason for this effect.

Most importantly, however, the fact that the talkers with PD did not show the expected patterns of density on dispersion for the high-frequency words may compromise their intelligibility. This finding suggests to us two dual sets of follow-up studies. The first of these should examine whether the failure to modulate the dispersion of high- and low-density high-frequency words is maintained in the connected speech of individuals with PD and, if so, if this failure contributes to their decreased speech intelligibility. Second, studies should examine whether this failure can be linked to a difficulty in the formulation of speech related to problems of phonological processing.

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