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Research Note

Healthy Communication Partners Modify Their Speech When Conversing With Individuals With Parkinson's Disease

Nichola Lubold,[a] Megan M. Willi,[b] Stephanie A. Borrie,[c] Tyson S. Barrett,[d] and Visar Berisha[a]

Purpose: For individuals with Parkinson's disease (PD), conversational interactions can be challenging. Efforts to improve the success of these interactions have largely fallen on the individual with PD. Successful communication, however, involves contributions from both the individual with PD and their communication partner. The current study examines whether healthy communication partners naturally engage in different acoustic–prosodic behavior (speech compensations) when conversing with an individual with PD and, further, whether such behavior aids communication success.
Method: Measures of articulatory precision, speaking rate, and pitch variability were extracted from the speech of healthy speakers engaged in goal-directed dialogue with other healthy speakers (healthy–healthy dyads) and with individuals with PD (healthy–PD dyads). Speech compensations, operationally defined as significant differences in healthy speakers' acoustic–prosodic behavior in healthy–healthy dyads versus healthy–PD dyads, were calculated for the three speech behaviors. Finally, the relationships between speech behaviors and an objective measure of communicative efficiency were examined.
Results: Healthy speakers engaged in speech characterized by greater articulatory precision and slower speaking rate when conversing with individuals with PD relative to conversations with other healthy individuals. However, these adaptive speech compensations were not predictive of communicative efficiency.
Conclusions: Evidence that healthy speakers naturally engage in speech compensations when conversing with individuals with PD is novel, yet consistent with findings from studies with other populations in which conversation can be challenging. In the case of PD, these compensatory behaviors did not support communication outcomes. While preliminary in nature, the results raise important questions regarding the speech behavior of healthy communication partners and provide directions for future work.

Hypokinetic dysarthria typified by imprecise articulation, prosodic abnormalities, disturbance of speech rate, and low vocal volume is common in Parkinson's disease (PD; Duffy, 1995), with approximately 50%–80% of affected individuals developing a motor speech disorder and exhibiting reduced speech intelligibility after onset (Hartelius & Svensson, 1994; Miller et al., 2007). This speech production disorder, in addition to any number of comorbidities that can accompany PD, often results in reductions in the ability to communicate effectively, leading to social isolation and detrimental effects on an individual's quality of life (Miller et al., 2006). Clinical strategies for treating hypokinetic dysarthria have primarily targeted speech production of the individual with PD (e.g., Lee Silverman Voice Treatment; Ramig et al., 1995). This places much of the demand and the responsibility for improving communication success on the individual with PD. Within the last decade, research in dysarthria has begun to embrace the notion that communication is a two-way street and that the role of the healthy communication partner may be equally important to communication success (e.g., Bloch & Barnes, 2020; Liss, 2007). For example, Borrie et al. (2012, 2018) have demonstrated that familiarizing listeners with the speech of talkers with hypokinetic dysarthria secondary to PD results

[a]School of Electrical, Computer, and Energy Engineering, Arizona State University, Tempe
[b]Communication Sciences and Disorders Program, California State University, Chico
[c]Department of Communicative Disorders and Deaf Education, Utah State University, Logan
[d]Department of Psychology, Utah State University, Logan
Correspondence to Nichola Lubold: nichola.lubold@asu.edu

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in improved understanding of the degraded speech signal, advancing perceptual training as a viable option for including the healthy communication partner in the management of hypokinetic dysarthria. The outcome of this focus on the communication partner has facilitated our understanding of how healthy partners perceive and adapt their speech perception systems in response to the speech of individuals with PD. However, little is known about the speech production behaviors of the healthy partners when conversing with individuals with PD.

The hypo–hyper (H&H) theory of speech production (Lindblom, 1990) makes predictions about how healthy communication partners may change their speech when conversing with individuals with PD. While primarily focused on articulation, the H&H theory characterizes the control that speakers have over their speech productions and how this control can be used to maximize communication efficiency in different communicative situations. The H&H theory proposes that speakers change the articulatory clarity of their speech along a hypo–hyper continuum in order to balance the effort of speech production against the need for effective communication (Lindblom, 1990). Hypo-articulated speech demands less articulatory effort but requires a greater degree of signal-independent information, such as the listener's knowledge or contextual information. Hyperarticulated speech demands more articulatory effort but is thought to provide greater acoustic clarity to improve understanding. Essentially, speakers will preferentially default to less precise articulation whenever possible and will engage in higher cost, effortful speech only when they perceive their listener requires greater acoustic clarity for effective communication.

Indications of the H&H model in practice have been found across several studies exploring speech production changes in different challenging communicative conditions. Hazan and Baker (2011), for example, showed that healthy speakers modify their speech to enhance clarity when interacting with healthy individuals who are experiencing an adverse listening condition. For example, speakers may increase vowel space and speak more slowly to individuals experiencing a simulated cochlear implant or to second language learners, and they may speak louder and with greater pitch variability to individuals in noisy environment (Hazan & Baker, 2011; Scarborough et al., 2007; Uther et al., 2007). Granlund et al. (2018) found evidence that older children will adapt their speech in similar listener-oriented ways (expanded vowel space, fewer words, increased intensity, increased pitch range) when conversing with a peer with hearing impairment, and Borrie, Wynn, et al. (2020) found evidence of hyperarticulation in the speech of a confederate conversing with patients with traumatic brain injury. A phenomenon termed *elderspeak* also exists, where healthy speakers elevate pitch, decrease speech rate, increase intensity, and use fewer words when conversing with older adults (Kemper & Harden, 1999; Williams et al., 2009). These changes in behavior are presumably to increase clarity and understanding where there is a hearing impairment and/or cognitive decline, though use of elderspeak is not necessarily cued by hearing or comprehension problems (Kemper & Harden, 1999; Kemper et al., 1996, 1995). Collectively, the results suggest that healthy speakers naturally and spontaneously utilize intelligibility-enhancing strategies when they perceive that their partner may have difficulty understanding their intended message, and there are communication breakdowns.

Conversations with individuals with PD are prone to communication breakdowns due to the presence of hypokinetic dysarthria and the negative listener impressions that this speech disorder evokes. Speakers with dysarthria are more likely than healthy talkers to be perceived as being less competent and capable, even when they are not less competent or capable (Fox & Pring, 2005). When listeners were asked to listen to and rate discourse samples from individuals with PD and hypokinetic dysarthria, negative impressions of the individuals with PD were highly prevalent, with impressions that the individuals with PD were less interested, involved, happy, and friendly (Jaywant & Pell, 2010). These negative impressions are not linked to linguistic content but were strongly correlated with acoustic properties of the degraded speech signal. Additionally, PD is considered to be a disease of old age, with only 5% of cases presenting symptoms before 60 years of age (Reeve et al., 2014); the mean age for the corpus utilized here is 69 years of age. While this age range is younger than that used in most explorations (average age is 73–82 years; Kemper & Harden, 1999; Kemper et al., 1996; Williams et al., 2009), healthy speakers may still respond with similar productions. Given these communicative challenges, the speech production behaviors of healthy speakers conversing with individuals with PD are of interest, and it seems probable that healthy speakers engaging in conversations with individuals with PD will behave in a similar manner as seen in previous studies of other challenging communicative contexts.

The Current Study

In the current study, we investigate the speech production behaviors of healthy speakers when they converse with individuals with PD by making use of two existing corpora: healthy speakers engaging in conversation with individuals with PD (healthy–PD dyads; Borrie, Barrett, et al., 2020) and healthy speakers talking to other healthy speakers (healthy–healthy dyads; Borrie et al., 2019). The healthy–PD dyads consisted of conversations between a younger adult and older adult with PD, while the healthy–healthy dyads consisted of conversations between two younger adults, resulting in a notable discrepancy in the differences between participants' ages between the two corpora. The primary variable of interest in the current study is dyad type; however, we acknowledge the discrepancy regarding age and its potential impact on the results. In all analyses for the current study, we control for age differences between healthy participants and participants with PD. While the age differences limit how much one can attribute results to elderspeak versus the presence of dysarthria, we are interested in how healthy speakers holistically respond to individuals with PD, which, as noted, is a disease that typically presents later in life. We evaluate the speech behaviors in the healthy–PD corpus relative to the healthy–healthy corpus and interpret observed changes in the healthy speakers' speaking behaviors as compensatory behavior. Furthermore, we examine whether these speech behaviors are predictive of an objective measure of communication success, which we assess as communicative efficiency. We use the H&H theory as a framework for investigating how healthy speakers compensate their speech on a set of acoustic–prosodic features conceptualized along the hyper–hypo continuum. The hyperend of each acoustic–prosodic feature dimension can be operationally defined as the end that maximizes clear speech (see Smiljanić & Bradlow, 2009, for a review). This includes hyperarticulation in the form of acoustic vowel space expansion and increased duration (Ferguson & Kewley-Port, 2007; Hazan & Baker, 2011; Smiljanić & Bradlow, 2005), decreased speaking rate (Hazan & Baker, 2011; Picheny et al., 1985; Smiljanić & Bradlow, 2005; Uchanski et al., 1996), and increased pitch variability (Smiljanić & Bradlow, 2005). For this work, we explore hyperarticulation in the form of articulatory precision or how clearly speakers articulate their spoken productions, along with speaking rate and pitch variability.

Our first research question focused on whether healthy speakers modify their speech productions, asking (a) "Is the acoustic–prosodic behavior of healthy speakers different in conversations with individuals with PD relative to conversations with healthy individuals?" Based on the H&H theory and work with older adults, we hypothesized that healthy speakers would gravitate toward the hyperend of the continuum when conversing with individuals with PD, engaging in acoustic–prosodic behaviors that are associated with enhanced intelligibility, including increased articulatory precision, decreased speaking rate, and increased pitch variability. Our second research question focused on the relationship between these acoustic–prosodic changes and communicative efficiency, asking (b) "Do healthy speakers' acoustic–prosodic compensations predict communicative efficiency in healthy–healthy dyads and healthy–PD dyads?" Based on the H&H theory in which speakers modify their speech production to support message exchange, we hypothesized a positive relationship between speech behavior and communicative efficiency in both dyad types. More specifically, we hypothesized that acoustic–prosodic behavior reflective of the hyperend of the continuum would be more predictive of success for healthy speakers talking to individuals with PD where greater acoustic clarity supports more effective communication in a challenging communicative context. For healthy speakers talking to healthy speakers, we hypothesized that acoustic–prosodic behavior reflective of the hypo-end of the continuum would be more predictive of success as the ability to engage in lower cost, lower effort speech may lead to greater communicative efficiency.

Method

Corpora

This study utilized existing corpora of spoken dialogue elicited from healthy–healthy and healthy–PD dyads (Borrie, Barrett, et al., 2020; Borrie et al., 2019). The healthy–healthy dyads involved 114 native speakers of American English, with no self-reported history of speech, language, hearing, or cognitive impairment. In contrast, the healthy–PD corpus involved 52 healthy speakers (same criteria as above) paired up with one of 52 individuals presenting with dysarthria. The individuals with dysarthria were also speakers of American English but had a clinical diagnosis of a dysarthria as evaluated by a speech-language pathologist not associated with this study. As described by Borrie, Barrett, et al. (2020), while dysarthrias of various etiologies were included in the data collection, the majority had a diagnosis of PD (n = 47). For this study, we focus solely on the individuals with PD. In this subset, dysarthria severity ranged from mild (n = 23) to mild–moderate (n = 10) to moderate (n = 10) to severe (n = 4). Dysarthria severity ratings were based on perceptual estimates from the speech-language pathologist who diagnosed the presence of dysarthria. Individuals were excluded from the study if concomitant impairments in speech (e.g., apraxia of speech) or language (e.g., aphasia) were identified. An informal assessment did not indicate the presence of any perceptual or comprehension difficulties that would interfere with dialogue task engagement for any of the participants, including those with PD. Outside the consideration of dysarthria, participants were randomly paired up to form dyads (57 healthy–healthy dyads and 47 healthy–PD dyads).

There is a notable discrepancy in participant age across the two corpora. For the healthy–PD dyads, the average age of the speakers was 68.9 years (SD = 10.7), and the average of age of their healthy partners was 25.7 years (SD = 6.6). For the healthy–healthy dyads, the average age of the speakers was 22.9 years (SD = 2.2). In our analyses, we control for age differences between healthy participants and participants with PD as best as possible given the limitations of the corpora. Age data were not available for four of the speakers with PD. As such, only 43 of the 47 healthy–PD dyads were included in the current analyses. Additionally, gender was not controlled for when forming dyads, so some dyads were female–female (healthy–healthy n = 43, healthy–PD n = 16), other dyads were female–male (healthy–healthy n = 13, healthy–PD n = 21), and a few were male–male (healthy–healthy n = 1, healthy–PD n = 6).

In the collection of the corpus, the conversations were task-oriented, elicited by the Diapix task (Baker & Hazan, 2011; Van Engen et al., 2010). The Diapix task is a collaborative "spot-the-difference" activity where participants are each given an image of a similar scene, but the two images differ in 10 small details. Participants are instructed to not show their image to their partner. The task for each dyad is to identify the differences, using verbal communication, as quickly and as accurately as possible within 10 min, at which point recordings were stopped. This task provides a measure of communicative efficiency, defined as the total number of differences participants identified in the allotted time: Relatively low and high numbers of identified differences indicate relatively high and low success. Dyads could complete as many picture pairs as time allowed; no dyad completed more than three picture pairs, and thus, the scores ranged from 10 to a max of 30, with an average of 19.2 (*SD* = 5.10) for healthy–healthy dyads and an average of 12.3 (*SD* = 4.40) for healthy–PD dyads. Previous studies of these corpora report no significant relationships between communicative effectiveness and dysarthria severity or between communicative effectiveness and the gender composition of dyads; although it is acknowledged that the healthy–PD corpus was not developed with severity and gender as a target of interest. Additional details of the conversation task, instructions, and recording equipment are specified in the original studies.

Processing Audio Recordings

Trained research assistants manually annotated the audio recordings by speaker, identifying the beginning and end of each spoken utterance as interpausal units (IPUs). An IPU is a unit of speech from a single speaker separated from any other speech by at least 50 ms (Levitan & Hirschberg, 2011). Manual identification of IPUs ensured stop closures were not identified as boundaries. Adjacent IPUs are consecutive IPUs uttered by two different speakers. With this definition, overlap is allowed. Across both corpora, adjacent IPUs make up 71.2% of the dialogue. Some dyads had a greater dialogue exchange rate, resulting in more adjacent IPUs than other dyads. The mean and standard deviation for adjacent IPUs for healthy–healthy and healthy–PD dyads are reported in Table 1. Audio recordings were normalized using a standard loudness normalization procedure based on a reference level, ensuring that the resulting normalized signal was within −1 to 1 to avoid peak clipping. Additionally, all sound files were down-sampled to 16 kHz prior to feature extraction.

Orthographic transcriptions for all adjacent IPUs were also obtained. The orthographic transcriptions came from a third-party service, GoTranscript (https://www.gotranscript.com). GoTranscript employs native English speakers and uses a multistep process in which transcripts are reviewed, proofread, and checked for quality to ensure accuracy. Third-party services have become a common approach for generating reliable transcriptions (Eskenazi et al., 2013).

Table 1. Descriptive statistics for the two dyad corpora used in the current study.

Variable	Healthy–healthy dyads	Healthy–PD dyads
No. of dyads	57	43[a]
Average age difference (*SD*)	2.2 (1.8)	41.1 (9.5)
Adjacent IPUs (*SD*)	184.2 (39.3)	168 (49)
Dialogue length (min)	10.5	11.1
Utterance length (words)	5.98	5.64
Male–male dyads	1	6
Female–female dyads	43	16
Female–male dyads	13	21
Total healthy female speakers	99	31
Total healthy male speakers	15	12

Note. PD = Parkinson's disease; IPU = interpausal unit or pause-free units of speech by a single speaker.

[a]Data for 47 healthy–PD dyads were collected, but age data were not available for four of the speakers, so 43 are included in the analyses.

Acoustic–Prosodic Feature Extraction

Articulatory Precision

To extract a measure of articulatory precision, we utilized an approach to automatically score pronunciation (Stegmann et al., 2020; Tu et al., 2018; Witt & Young, 2000), which assesses pronunciation as the log-posterior probability of aligned phonemes normalized by phoneme duration. With this methodology, we can obtain an articulatory precision score for every phoneme in the corpus (see Lubold et al., 2019). The first step is to align the orthographic transcriptions for each IPU at the phoneme level using an acoustic model for English based on the LibriSpeech corpus (Panayotov et al., 2015). The alignment provides the start and end frame indices for each phoneme. A single coder manually evaluated the results of the automated alignment for 20% of the dialogue using Praat (Boersma, 2002) to ensure that the start and end indices were accurately captured. With the alignment and the audio, the articulatory precision score for a phoneme p was then defined as

$$\begin{aligned} \mathrm{APS}(p) &= \log(P(p|O^p))/|O^p| \\ &\approx \log\left[\frac{P(O^p|p)}{\max_{q\in Q} P(O^q|q)}\right]/|O^p|, \end{aligned} \quad (1)$$

where O^p is the corresponding acoustic segment, $|O^p|$ is the number of frames in the segment, and Q is the set of all phonemes. The above equation assumes equal priors for all phonemes. If the phoneme returned by the acoustic model is the same as the target phoneme p, then the articulatory precision score is equal to 0. Otherwise, the score will be negative; the smaller the score (i.e., the farther from zero), the farther the pronunciation is from that defined by the LibriSpeech corpus. Because the LibriSpeech corpus is read speech, this measure is an evaluation of articulatory precision as defined by "read" speech. We interpret scores further from zero as less precise. We averaged the individual phoneme precision scores to obtain scores per speaker and per IPU. Mean articulatory precision for each speaker was then calculated by averaging the articulatory precision over all their IPUs.

Speaking Rate

To extract a measure of speaking rate, we utilized the orthographic transcriptions to calculate the number of words uttered per minute such that speaking rate (wpm) = total words ÷ number of minutes. Words were identified based on the orthographic transcriptions. Neither nonspeech utterances (i.e., filled pauses) nor between-turn silences were included in the calculation of speaking rate. Speaking rate was first calculated per IPU for each speaker based on the total words and the total length of each IPU. The mean speaking rate for each speaker was calculated by averaging the speaking rate over all their IPUs.

Pitch Variability

To extract a measure of pitch variability, we utilized openSMILE (Eyben et al., 2010). We extracted the fundamental frequency standard deviation (i.e., pitch variation) by first estimating the pitch using an autocorrelation-based method and then calculating the standard deviation. Based on speaker gender, pitch range settings were set for males and females, separately, which has been shown to increase accuracy of automated analyses (Vogel et al., 2009). For males, the floor was set at 75 Hz, and the pitch ceiling was set at 250 Hz. For females, the floor was set at 100 Hz, and the ceiling was set at 500 Hz. Frame length was set at 25 ms. The pitch variation was calculated per IPU. Mean pitch variability for each speaker was then calculated by averaging the pitch variation extracted from all their IPUs.

Statistical Analysis

Multiple regression was used to answer our first research question of whether healthy speakers exhibit differences in speech behavior when conversing with individuals with PD. We compared their behavior to healthy speakers talking to other healthy speakers by testing whether there were significant differences in the three acoustic–prosodic features across the dyad type (healthy–healthy and healthy–PD). We present three models in total, one model for each feature.

For all three models, we first explored the contribution of age difference and gender by entering these variables into an initial, first-stage regression analysis before evaluating the additional contribution of dyad type. For articulatory precision, we also adjusted the model for potential variance due to speaking rate by adding it to the first stage of the analysis. For the model for speaking rate, we controlled for the effects of utterance length in the first stage of the regression. Then, in the second stage of the multiple regression analyses for all three models, we entered dyad type to evaluate the potential effects of context. The interactions between age differences and dyad type with respect to differences in the three acoustic–prosodic features were not significant for any of the features explored; we therefore exclude it from the analyses reported. The relevant assumptions of multiple regressions were also tested. Residual scatter plots indicated the assumptions of normality, linearity, and homoscedasticity were all satisfied (Hair et al., 1998).

To answer our second research question regarding the relationship between acoustic–prosodic compensation and communicative efficiency, we evaluated whether the three acoustic–prosodic speech features of healthy speakers in different dyads relate to success using linear regression. This allowed us to determine if the overall model for predicting communicative efficiency is significant and whether there are different effects for the different dyad types. Each feature was entered as an independent variable, along with an independent variable for the dyad type, with communicative efficiency as the dependent variable.

As a secondary exploration of the data, we investigated the potential relationship between the three acoustic–prosodic speech features of interest and two factors that may influence these features: dysarthria severity and gender. However, it is important to note that data collected for this study were not set up to target gender or severity (i.e., unequal spread of gender dyad composition and participants with mild, mild–moderate, moderate, moderate–severe, and severe dysarthria). We controlled for gender in the analyses, and additionally, we used Pearson correlations to assess the potential influence of a dyad's gender composition and severity of dysarthria on a healthy speaker's acoustic–prosodic features.

Results

The means and standard deviations for articulatory precision, speaking rate, and pitch variability are given in Table 2. We examined the correlations between the three speech variables and communicative efficiency. None of the variables were strongly or even moderately correlated, with $|r| \leq .3$ for all relationships, as shown in Table 3. We did observe a small but significant correlation between speaking rate and articulatory precision ($r = -.14$, $p = .03$), and communicative efficiency is significantly correlated with all three speech variables.

In the following sections, we describe the three regression analyses on articulatory precision, speaking rate, and pitch variability. The coefficients for each regression analysis are given in Table 4, and the relationships between the healthy–healthy and healthy–dysarthric groups are depicted in Figure 1.

Articulatory Precision

The first stage of the multiple regression analysis on articulatory precision controlled for the effect of age difference and speaking rate on the articulatory precision produced by healthy speakers in healthy–healthy dyads and healthy–PD dyads. The initial model controlling age differences, gender, and speaking rate was significant, $F(2, 154) = 10.1$, $p < .001$, explaining 16% of the variance between speakers on articulatory precision. Introducing dyad type in the second stage, the new model explains an additional 8% of the variance in articulatory precision, and this was significantly better than the first model, $F(3, 153) = 15.11$, $p < .001$. Results revealed that healthy speakers talking to individuals with PD significantly increased their precision by 0.28 units in comparison to healthy speakers talking to other healthy

Table 2. Means and standard deviations for the three acoustic–prosodic speech behaviors.

Variable	Healthy–healthy	Healthy–PD	Total
Articulatory precision	−1.87 (0.39)	−1.47 (0.41)	−1.76 (0.43)
Speaking rate (wpm)	3.57 (0.38)	3.44 (0.35)	3.53 (0.37)
Pitch variability (Hz)	34.22 (11.23)	28.41 (9.26)	32.6 (10.99)

Note. PD = Parkinson's disease.

Table 3. Correlation results for communicative efficiency, articulatory precision, speaking rate, and pitch variability (N = 157).

Variable	Articulatory precision	Speaking rate	Pitch variation	Communicative efficiency
Articulatory precision	—			
Speaking rate	−.14$^+$	—		
Pitch variation	−.01	.07	—	
Communicative efficiency	−.20*	.30**	.18$^+$	—

*p < .01. **p < .001. ^+p < .05.

speakers. The measure for articulatory precision is a relative measure based on the preciseness of the read speech in the LibriSpeech corpus; to put it into context, the standard deviation for the articulatory precision of healthy controls was 0.4 so healthy speakers talking to individuals with PD approached 1 *SD* of increased precision in comparison to healthy speakers talking to other healthy speakers.

Speaking Rate

As with articulatory precision, the first stage of the multiple regression on speaking rate controlled for the effects of age differences and utterance length on the speaking rate produced by healthy speakers in healthy–healthy dyads and healthy–PD dyads. The initial model controlling age differences, gender, and utterance length was significant, $F(2, 154) = 10.43$, $p < .001$, explaining 16% of the variance between speakers on speaking rate. Introducing dyad type in the second stage, the new model explains an additional 4% of the variance in speaking rate, and this was significantly better than the first model, $p = .01$. Results revealed that healthy speakers talking to individuals with PD spoke at a rate of 0.47 words per minute slower than healthy speakers talking to other healthy speakers. This speaking rate reduction occurred above and beyond the effects of age differences, gender, and average utterance length.

Pitch Variability

Finally, the first stage of the multiple regression on pitch variability controlling for the effects of age differences and gender was significant, $F(1, 155) = 84.7$, $p < .001$, with 52% of the variance in pitch variation explained by gender and age. Introducing dyad type in the second stage, the new model does not explain much additional variance (0.1%). After controlling for gender, we find few differences in pitch variation between healthy speakers talking to speakers with PD and healthy speakers talking to other healthy speakers.

Communicative Efficiency

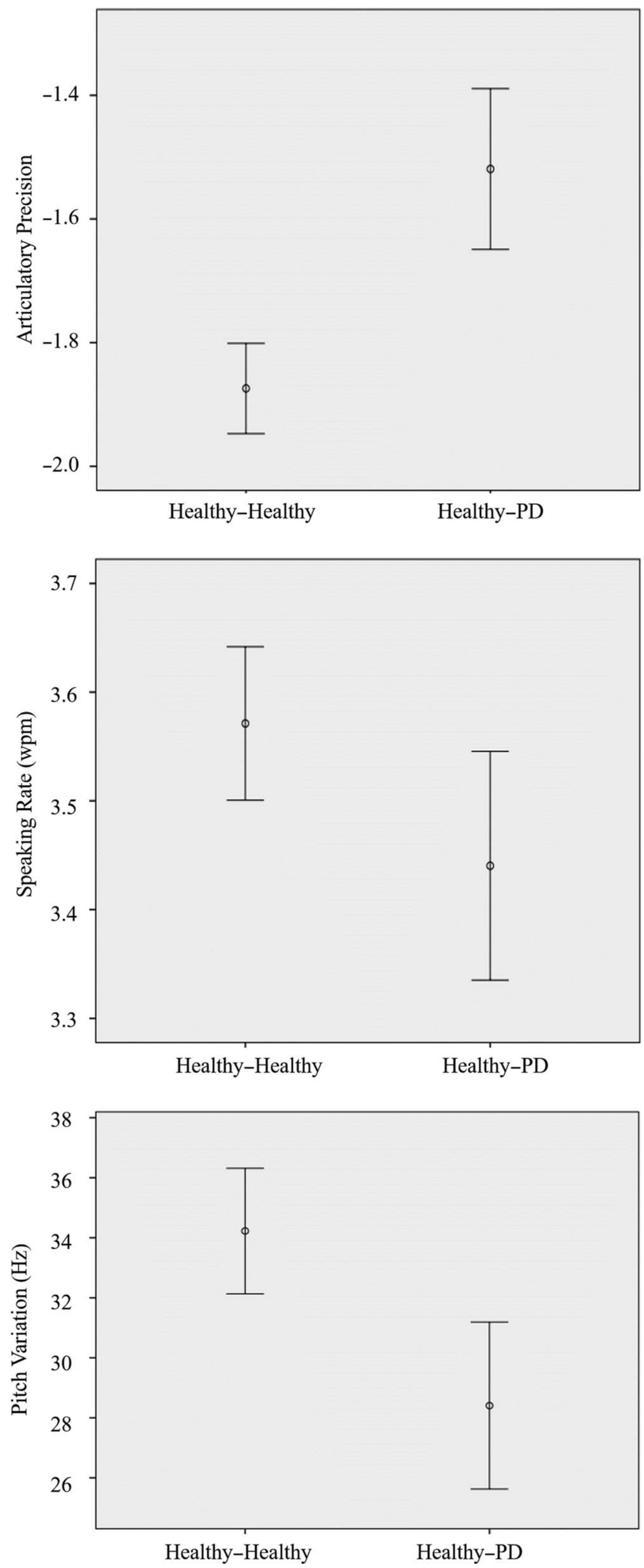
Linear regression revealed that the overall model for communicative efficiency is significant, $F(4, 149) = 18.39$, $p < .001$. Articulatory precision, $B = -2.74$, $p = .008$, was

Table 4. Summary of hierarchical regression analysis for dyad type on the three acoustic–prosodic speech behaviors (N = 157).

Variable		Model 1			Model 2		
		B	*SE B*	β	*B*	*SE B*	β
Articulatory precision	Age difference	0.02	0.01*	0.23	0.02	0.01$^+$	0.15
	Gender	0.00	0.08	0.00	0.05	0.08	0.04
	Speaking rate	−0.36	0.08**	−0.32	−0.31	0.08**	−0.27
	Healthy–healthy (constant)				−1.43	0.37	
	Healthy–PD				0.28	0.07**	0.29
	R^2		.16			.24	
	F for change in R^2		10.10**			15.11**	
Speaking rate	Age difference	−0.01	0.00*	−0.22	.01	0.01	0.38
	Gender	0.00	0.07	0.00	−.04	0.07	−0.05
	Utterance length	0.14	0.03*	0.41	0.14	0.03*	0.40
	Healthy–healthy (constant)				3.25	0.27	
	Healthy–PD				−0.47	0.21*	−0.57
	R^2		.16			.20	
	F for change in R^2		10.43**			5.81*	
Pitch variability	Age difference	−0.07	0.03	−0.11	−0.01	0.12	−0.01
	Gender	20.19	1.60**	0.70	19.95	1.78**	0.70
	Healthy–healthy (constant)				19.32	5.43	
	Healthy–PD				−2.48	4.94	−0.01
	R^2		.52			.52	
	F for change in R^2		84.75			0.23	

*p < .01. **p < .001. ^+p < .05.

Figure 1. Differences in healthy speakers' production behaviors in terms of articulatory precision, speaking rate, and pitch variability in healthy–healthy dyads and healthy–PD dyads.



significantly related to communicative efficiency with less precise articulation associated with greater communicative efficiency. Speaking rate and pitch variation were not significantly related to communicative efficiency. The results are given in Table 5.

When the effects of healthy speakers by dyad type are analyzed, we find the healthy–healthy dyads appear to be driving these results, $F(3, 110) = 2.94$, $p = .03$, with significant effects for articulatory precision, $B = -2.99$, $p = .01$. The model for healthy speakers in healthy–PD dyads was not significantly predictive of communicative efficiency, $F(3, 39) = 0.61$, $p = .61$.

Secondary Analysis of Relationships

There was no significant relationship between dysarthria severity and a healthy conversational partner's articulatory precision, $r(43) = -.04$, $p = .82$, speaking rate, $r(43) = -.002$, $p = .99$, or pitch variability, $r(43) = .25$, $p = .09$. The gender composition of the healthy partner's dyad was also not related to articulatory precision, $r(157) = .09$, $p = .27$, or speaking rate, $r(157) = .02$, $p = .85$. However, the gender composition was significantly related to pitch variability, $r(157) = .36$, $p < .001$, which aligns with our findings regarding pitch variability.

Discussion

The current study found that healthy speakers modified their speech when talking to individuals with PD. Specifically, we observed that spoken productions of healthy speakers conversing with individuals with PD were characterized by increased articulatory precision and reduced speaking rate relative to healthy speakers conversing with other healthy individuals. Thus, our first hypothesis, that speakers would engage in acoustic–prosodic behaviors that support enhanced clarity when talking to individuals with PD, was largely supported. It is important to note that this is a preliminary investigation using two existing corpora. For the two measures that were significant, age difference together with measure-specific factors explained a greater amount of variation than dyad type: 16% versus 8% for articulatory precision and 16% versus 4% for speaking rate. While the measure-specific factors contribute significantly to the explained variance in these two cases, these results suggest that age difference is an influential factor on speaker behavior and should be controlled for in future studies. In addition to the effect of age, the regression analyses show that dyad type is linked to variance in healthy speakers' behaviors.

Findings of increased articulatory precision and reduced speaking rate in challenging communicative contexts are consistent with findings in which healthy speakers modify their speaking rate and vowel space when conversing with individuals in adverse listening conditions, with older adults, children, and second-language learners (Granlund et al., 2018; Hazan & Baker, 2011; Kemper & Harden, 1999; Scarborough et al., 2007; Uther et al., 2007). As previously noted, communication challenges are common in conversations with individuals with PD (e.g., Bloch et al., 2015; Bloch & Wilkinson, 2009). The current findings suggest that healthy speakers change their speech behavior, presumably in an attempt to compensate for these challenges, in line with predictions of the H&H theory.

We found that the acoustic–prosodic modifications that healthy speakers made when talking to individuals with PD were not related to the measure of communicative efficiency. That is, neither increased articulatory precision nor slower speaking rate predicted success for healthy speakers talking to individuals with PD. One explanation for why healthy speakers may be modifying their speech even though it does not facilitate success may be related to listener impressions. Speakers with dysarthria are perceived as being less competent and capable. It is possible that a healthy partner's negative impression of their partner with PD's degraded speech signal is driving their compensatory behavior. Alternatively, it is possible that most of the healthy speakers talking to individuals with PD are already compensating with more precise, slower, and less variable speech. This creates a ceiling effect where the speakers are clustered on the hyperend of the hypo–hyper continuum. When combining both sets of conversations, we observe a significant effect on success; this could be because they combined data exercises for the full range of the hyper–hypo continuum. To fully validate whether these compensatory strategies are beneficial, a study in which healthy speakers are instructed to consciously engage in hyper- or hypo-styled speaking is required.

Table 5. Summary of regression analysis for three acoustic–prosodic features on communicative efficiency ($N = 157$).

Variable		***B***	***SE B***	**β**
Communicative efficiency	Pitch variation	–0.01	0.04	–0.17
	Speaking rate	0.64	1.11	0.04
	Articulatory precision	–2.74	1.02*	–0.20
	Healthy–healthy (constant)	18.09	4.75	
	Healthy to dysarthric	–5.88	0.97**	–0.46
	R^2		.33	
	F		18.39**	

*$p < .01$. **$p < .001$.

In support of our hypothesis in healthy–healthy dyads, we found that acoustic–prosodic speech behavior toward the hypo-end of the H&H continuum was related to communicative efficiency, with less precise articulation associated with greater success. The more successful healthy–healthy dyads were, the more they exhibited hypo-articulation in the form of less precise articulation. These results are consistent with the H&H theory, in which speakers can get away with less articulatory effort as long as they share a greater degree of signal-independent information such as listener knowledge or contextual information, meaning speakers can shift to more hypo-articulate speaking behaviors as they become more effective at the task and nonverbal communication. With reduced articulatory effort and a faster speaking rate, dyads may have been able to identify differences faster and were thus rewarded with higher objective success scores, though we did not observe a relationship between speaking rate and communicative efficiency.

Limitations and Future Directions

There are several limitations with this work. As previously mentioned, the corpora utilized for this study differed in the age differences between dyad types. While we controlled for the effects of age difference in analyses, there is potentially additional variance in speaking behavior due to age that was above and beyond what we could capture with age differences. To fully understand the extent to which speakers may compensate based on the dysarthria of the individual versus elderspeak due to age bias or elderspeak due to hearing loss, a study incorporating additional targeted and controlled corpora is needed. More targeted and controlled corpora are also needed to reach a firm conclusion on the roles of gender and severity, as these were not evenly distributed in the exploratory corpora used here. In addition, we did not account for the productions of the speaker with PD in the current analyses. However, conversation is a joint activity and any measure of communication success is ultimately based on contributions from both interlocutors. Indeed, a joint measure of speech entrainment, even when reduced in healthy–PD dyads, has been shown to predict the same objective measure of communicative efficiency (Borrie, Barrett, et al., 2020; Borrie et al., 2015). This suggests the need to consider conversation holistically by including the interactive effects of speech behavior and considering multiple coordinative strategies (i.e., entrainment and compensation) in tandem (see Borrie, Wynn, et al., 2020, for a case study). It is also important to note that different dyads will also approach the Diapix task differently, with more efficient and less efficient strategies (i.e., going from left to right or top to bottom), making variances in efficiency difficult to normalize when comparing across two different speaker groups. Future work should consider a variety of other measures that capture communication success (e.g., measures of information exchange, self-reported evaluations, and third-party ratings) and stage a variety of interaction situations, including those that are not dependent on a time-based metric.

While exploratory at this point, with further investigation, findings may have implications for the role of the healthy communication partner when conversing with individuals with PD. The speech production changes that healthy speakers make when conversing with individuals with PD appear to be naturally and spontaneously occurring largely (if not completely) reflective of intelligibility-enhancing strategies. While we did not observe a positive relationship between these adaptations and success, we also did not observe a negative relationship, suggesting that such compensatory behavior did not do any harm relative to our measure of communicative efficiency. We have noted that more holistic measures of communication success are warranted and should be explored, including information about how the individual with PD feels about the compensations. Indeed, with such further investigation combining other types of coordinative behaviors, there may be potential for therapeutic training for the communication partners of individuals with PD. For example, if healthy partners practice a cohesive clear speech strategy, can this enhance communication success in this population? Are there other accommodating strategies and compensatory behaviors healthy partners can model that may improve communication success? If healthy partners can be trained on constructive speech production strategies, this may have positive implications for the communicative environment of individuals with PD.

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