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Clear Speech Variants: An Investigation of Intelligibility and Speaker Effort in Speakers With Parkinson's Disease

Kaila L. Stipancic,[a] Frits van Brenk,[a,b] Alexander Kain,[c] Gregory Wilding,[d] and Kris Tjaden[a]

[a] Department of Communicative Disorders and Sciences, University at Buffalo, NY [b] Utrecht Institute of Linguistics OTS, Utrecht University, the Netherlands [c] Department of Pediatrics, Oregon Health & Science University, Portland [d] Department of Biostatistics, University at Buffalo, NY

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ABSTRACT

Purpose: This study investigated the effects of three clear speech variants on sentence intelligibility and speaking effort for speakers with Parkinson's disease (PD) and age- and sex-matched neurologically healthy controls.

Method: Fourteen speakers with PD and 14 neurologically healthy speakers participated. Each speaker was recorded reading 18 sentences from the Speech Intelligibility Test in their habitual speaking style and for three clear speech variants: clear (SC; given instructions to speak clearly), hearing impaired (HI; given instructions to speak with someone with a hearing impairment), and overenunciate (OE; given instructions to overenunciate each word). Speakers rated the amount of physical and mental effort exerted during each speaking condition using visual analog scales (averaged to yield a metric of overall speaking effort). Sentence productions were orthographically transcribed by 50 naive listeners. Linear mixed-effects models were used to compare intelligibility and speaking effort across the clear speech variants.

Results: Intelligibility was reduced for the PD group in comparison to the control group only in the habitual condition. All clear speech variants significantly improved intelligibility above habitual levels for the PD group, with OE maximizing intelligibility, followed by the SC and HI conditions. Both groups rated speaking effort to be significantly higher for both the OE and HI conditions versus the SC and habitual conditions.

Discussion: For speakers with PD, all clear speech variants increased intelligibility to a level comparable to that of healthy controls. All clear speech variants were also associated with higher levels of speaking effort than habitual speech for the speakers with PD. Clinically, findings suggest that clear speech training programs consider using the instruction "overenunciate" for maximizing intelligibility. Future research is needed to identify if high levels of speaking effort elicited by the clear speech variants affect long-term sustainability of the intelligibility benefit.

Many patients with Parkinson's disease (PD) experience *dysarthria*, a neuromotor speech disorder affecting speech execution. Dysarthria often results in reduced speech intelligibility, defined as the degree to which a listener can recover the acoustic signal produced by a speaker (Yorkston et al., 1996). Reductions in speech intelligibility negatively affect quality of life in patients with PD (Miller et al., 2006; Spencer et al., 2020; van Hooren et al., 2016), and therefore, improving intelligibility is often a central goal of speech-language therapy (Duffy, 2020; Yorkston, 2010). With this goal in mind, treatments focused on increasing vocal loudness in patients with PD are common (for examples, see Broadfoot et al., 2019; Herd et al., 2012; Muñoz-Vigueras et al., 2020; Richardson et al., 2014); however, other behavioral techniques that

Correspondence to Kaila L. Stipancic: klstip@buffalo.edu. **Disclosure:** *The authors have declared that no competing financial or nonfinancial interests existed at the time of publication.*

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target global aspects of speech also show promise for improving intelligibility in patients with PD.

Adapting a clear style of speaking is a strategy talkers use to maximize intelligibility (Smiljanić, 2021; Smiljanić & Bradlow, 2009; Uchanski, 2008) and has been widely recommended as a component of behavioral treatment protocols aimed at improving intelligibility for speakers with dysarthria, including dysarthria secondary to PD (Beukelman et al., 2002; Yorkston, Hakel, et al., 2007). A clear speech style elicits a variety of acoustic adjustments at both segmental and suprasegmental levels, resulting in intelligibility improvements in neurotypical speech (Smiljanić, 2021). In addition, a growing number of studies have indicated the perceptual benefits of a clear speech style in individuals with dysarthria (Hanson et al., 2004; Park et al., 2016; Stipancic et al., 2016; Tjaden et al., 2014). Across studies, the reported magnitude of intelligibility gains as a result of adopting a clear speaking style is variable. A possible contributing factor to this variability is the instruction or cues provided to speakers to elicit clear speech. The present work sought to evaluate whether different instructions for eliciting clear speech affect intelligibility. This project also identified an additional consideration for determining feasibility of implementing different clear speech variants: the amount of effort a speaker employs to achieve a clear speech style.

Variability in Clear Speech Instructions

The instruction or cues for eliciting clear speech given to speakers is a possible contributing factor to the variable outcomes reported in previous literature (Smiljanić & Bradlow, 2009; Uchanski, 2008). Commonly used instructions include, "Speak clearly, so that a hearing-impaired person would be able to understand you" (Ferguson, 2004; Ferguson & Kewley-Port, 2002), "Talk like you are speaking to a listener with a hearing loss or who is a non-native speaker" (Smiljanić & Bradlow, 2005), "Produce the items as clearly as possible, as if I am having trouble hearing or understanding you" (Goberman & Elmer, 2005; Rosen et al., 2011; Whitfield & Goberman, 2014), "Pretend you are teaching words to second language learners" (Kang & Guion, 2008), and "Produce this sentence as clearly as possible by overenunciating or producing it as if you were speaking to someone with a hearing impairment" (Kuruvilla-Dugdale & Chuquilin-Arista, 2017). Although instructions to elicit clear speech vary widely across studies, work directly comparing the perceptual consequences of different clear speech instructions or the effects of differing instructions on speech production are sparse. Lam et al. (2012) compared a variety of acoustic measures obtained from sentences on the Assessment of Intelligibility of Dysarthric Speech (Yorkston et al., 1984) produced by healthy young adults in habitual, clear (SC; "while speaking clearly"), hearing impaired (HI; "speak as if speaking to someone who has a hearing impairment"), and overenunciated (OE; "overenunciate each word") speaking conditions. Results showed that, relative to the habitual speaking condition, the SC, HI, and OE conditions were associated with changes in measures of vowel production, speech timing, and vocal intensity, with the OE condition showing the largest acoustic changes relative to the habitual condition. This side-by-side comparison of clear speech variants indicated that the exact instruction used to elicit clear speech affects acoustic measures of speech production. A subsequent study by Lam and Tjaden (2013b) investigated whether the different instructions (the same instructions as those used in the Method section of this study) for eliciting clear speech reported by Lam et al. also affected judgments of intelligibility of the neurologically healthy speakers. The results showed that all clear speech variants were accompanied by increases in intelligibility, where the OE condition showed the largest improvements, followed by the HI and SC conditions, providing evidence that listeners are sensitive to the speech production adjustments elicited by different clear speech instructions. In addition, greater magnitudes of acoustic change in the nonhabitual conditions, including lax vowel space, articulation rate, and vocal intensity, were found to be associated with greater increases in intelligibility (Lam & Tjaden, 2013a). Although intelligibility differences across clear speech variants have been reported for young healthy speakers, it remains unknown if these findings will hold with clinical populations. For example, for some patients with PD, a neuromuscular constraint resulting in oromotor rigidity could limit articulatory/acoustic modulation (Pinto et al., 2017; Tsao & Weismer, 1997; Tsao et al., 2006), resulting in unaltered, rather than improved, intelligibility across clear speech variants.

Although the above studies examined speech of neurologically healthy individuals, a similar approach may assist in enhancing the therapeutic use of clear speech strategies for clinical populations with dysarthria. Lam and Tjaden (2016) investigated how clear speech variants affect acoustic measures of speech in speakers with PD and healthy control speakers. Of interest were both segmental (vowel space area, first moment coefficient differences for consonant pairs, second formant slopes of diphthongs, and vowel and fricative durations) and suprasegmental (fundamental frequency [f_o], sound pressure level [SPL], and articulation rate) acoustic measures. The results showed that the majority of acoustic measures differed between the variants of clear speech instruction and the habitual condition, but results were condition specific: The OE condition elicited the greatest magnitude of change for segmental measures (vowel space area and vowel durations) and the slowest articulation rates, whereas the HI

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condition elicited the greatest fricative durations and suprasegmental adjustments (f_o and SPL). The authors suggested that findings could be the result of task-specific interpretation of speech instructions. For example, the instructions used to elicit the HI condition might have led speakers to predominantly adjust suprasegmental aspects of speech at the respiratory–phonatory level, whereas the instructions used to elicit the OE condition may have led speakers to predominantly exaggerate articulatory gestures. The current study extends this line of inquiry to the perceptual consequences of different clear speech instructions for the same speakers and speech materials reported in Lam and Tjaden (2016).

Speaker Effort

As researchers examine how to best optimize behavioral speech protocols to enhance patient outcomes, factors outside of clinician variation in implementing a given behavioral speech treatment or protocol must also be considered. One factor that may influence implementation is the sustainability, or long-term maintenance, of the behavioral modification over time. The amount of effort required to complete a task is one element that may affect sustainability. Speaking effort is defined here as the overall amount of subjective exertion, physical and/or mental, that is required to produce speech. The concept of speaker effort is addressed in Lindblom's (1990) hypo- and hyperarticulation (H&H) theory of speech production. The H&H theory describes speech production on a continuum wherein talkers adjust their speech output for the needs of their listener. Conversational speech represents the "hypoarticulate" end of the continuum, and clear speech represents the "hyperarticulate" end of the continuum. According to Lindblom, a trade-off occurs between speech clarity and economy of effort, such that talkers minimize effort during habitually produced speech and increase effort when producing clear speech. Economy of effort has also been incorporated into more contemporary models of speech production (see Guenther et al., 2006; Perkell et al., 2002). In these models, greater or smaller articulatory displacements are associated with increased or decreased effort for speech, respectively. These models posit that articulatory trajectories typically ensure sufficient perceptual contrasts while minimizing speaking effort (Guenther & Perkell, 2004; Perkell et al., 2000). More simply, speakers will use the least amount of effort required for speech to be understood in the prevailing context.

Particularly in research examining the short-term effects of a speaking style on speech production, including the current study, evaluating the sustainability of a treatment strategy is challenging. In the biological and limb motor control literatures, authors consider how "costs" affect the utility of motor behaviors (Morel et al., 2017). For example, Cos (2017) discussed "cost" as the "devaluation of the benefit associated with an option due to its associated effort expenditure" (p. 2). In other words, as the amount of effort required to perform a behavior increases, the benefit of the behavior becomes undervalued, which subsequently decreases the likelihood that the behavior will continue. Stated in the terms of the clear speech variant literature, if a clear speech variant requires too much effort on the part of the speaker, the value of the intelligibility benefit derived from the clear speaking mode is degraded, and the speech modifications may be abandoned (Taylor et al., 2020). The relationship between speech production and effort is not a novel concept. Zipf (1965) studied the "principle of least effort" in human behavior and proposed that speakers use shorter words more frequently in discourse to economize time and effort in speech production. Therefore, balancing intelligibility benefit and speaker effort may be an important consideration for the feasibility of behavioral speech strategies and for improving adherence to treatment. Particularly for patients with PD who already have an increased sense of effort and fatigue (see reviews in Friedman et al., 2007, 2016; Marr, 1991) and who report higher levels of effort compared to healthy controls for speech tasks and activities of daily living (Solomon & Robin, 2005), implementing an overly effortful speech strategy or style may be impractical. Rather, consistent with Lindblom's (1990) economy of effort concept, a more feasible approach might be to select an instruction that elicits moderate speech change without overexerting the speaker.

Purpose

Prior work from our lab found the clear speech instruction "overenunciate each word" elicited the greatest magnitude of segmental change and the slowest articulation rates, whereas "speak to someone with a hearing impairment" elicited the greatest suprasegmental adjustments for both speakers with PD and age- and sex-matched neurologically healthy controls (Lam & Tjaden, 2016). The current study leveraged this database to examine whether the different clear speech instructions yield different magnitudes of intelligibility benefit, as well as different magnitudes of speaker effort. Knowledge of how these instructions affect functional communication, as well as speaker perception of effort, not only would strengthen their scientific evidence base but may also advance theoretical understanding of intelligibility and inform implementation of these techniques in clinical practice. Understanding the effect of instruction on intelligibility outcomes can also inform clear speech training programs (Caissie et al., 2005; Levitt et al., 2015; Park et al., 2016) to produce benefits in time- and

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effort-efficient ways. To this end, the current study addressed three research questions:

1. What is the effect of different clear speech instructions on speech intelligibility in individuals with PD, as compared to neurologically healthy controls?
2. What is the effect of different clear speech instructions on speaking effort in individuals with PD, as compared to neurologically healthy controls?
3. What is the relationship of speech intelligibility to speaking effort across the clear speech instruction variants?

Method

Speakers and Speech Materials

The study was approved by the institutional review board (IRB protocol number: 030-732229) through the University at Buffalo. All participants provided informed consent before completing study procedures. Speakers and speech materials are described in detail in Lam and Tjaden (2016). A total of 28 speakers were recruited for the study, including 14 participants (nine men, five women) with idiopathic PD and 14 age- and sex-matched neurologically healthy control participants (nine men, five women). Demographic information for the speakers is displayed in Table 1. Participants in both groups ranged from 55 to 81 years old, with a mean age of 68 years (*SD* = 7). Pure-tone thresholds were obtained at octave frequencies between 250 and 8000 Hz for all speakers in the UB Speech and Hearing Clinic. Screening results were provided to each speaker but did not exclude speakers from participating (see Sussman & Tjaden, 2012). Ten speakers in each group had thresholds of 40 dB or better in at least one ear at 1, 2, and 4 kHz (Darling & Huber, 2011; Weinstein & Ventry, 1983), with the other four participants in each group presenting with mild hearing loss. Thus, the same proportion of speakers in both groups exhibited mild hearing loss, as would be expected for this age cohort. None of the speakers used hearing aids, and all were able to follow verbal instructions.

Speakers were recruited from Western New York and reported speaking American English as a first

Table 1. Speaker demographic data.

Subject code	Sex	Age (years)	Years postdiagnosis	SLP-judged intelligibility (%)	SLP-judged scaled speech severity
			Neurologically healthy control speakers		
C01	Male	70		97.88	0.24
C02	Male	71		99.39	0.20
C03	Female	64		98.79	0.08
C04	Female	68		98.18	0.16
C05	Male	72		99.09	0.11
C06	Female	78		99.09	0.05
C07	Female	67		100.00	0.15
C08	Male	68		98.79	0.65
C09	Female	55		98.79	0.06
C10	Male	59		100.00	0.06
C11	Male	72		99.39	0.07
C12	Male	63		99.39	0.11
C13	Male	78		99.40	0.13
C14	Male	65		94.24	0.27
Control, *M* (*SD*)		67.86 (6.50)		98.74 (1.43)	0.17 (0.16)
			Speakers with Parkinson's disease		
PD01	Male	70	10	97.88	0.26
PD02	Male	71	3	97.88	0.26
PD03	Female	64	0	99.39	0.06
PD04	Female	69	7	97.27	0.38
PD05	Male	71	2	98.48	0.16
PD06	Female	80	10	98.48	0.72
PD07	Female	70	7	99.70	0.12
PD08	Male	65	13	98.48	0.10
PD09	Female	55	5	99.09	0.13
PD10	Male	62	8	99.09	0.13
PD11	Male	68	5	96.97	0.29
PD12	Male	65	5	98.79	0.30
PD13	Male	81	11	99.39	0.20
PD14	Male	65	6	90.00	0.62
PD, *M* (*SD*)		68.29 (6.72)	6.57 (3.63)	97.92 (2.42)	0.27 (0.19)

Note. SLP = speech-language pathologist; C = control speakers; PD = speakers with Parkinson's disease.

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language. All speakers had achieved at least a high school diploma, reported adequate vision or corrected vision for reading, and achieved a score of 26 or better on the Mini-Mental State Examination (Molloy, 1999). Control speakers denied history of neurological, speech, language, or hearing pathology. Speakers with PD reported no other history of neurological impairment other than PD, and any speech therapy received postdiagnosis was documented but did not exclude participants from the current study. Five speakers with PD reported previously participating in the Lee Silverman Voice Treatment (LSVT). Four of these individuals had completed the treatment program more than 2 years before the current study, and one speaker had completed the treatment more than a year before the current study. At the time of data collection, the speaker who had most recently completed LSVT and one other speaker with a history of LSVT were participating in weekly group therapy sessions practicing increased vocal loudness. All speakers were required to deny history of neurosurgical treatments (i.e., deep brain stimulation). Speakers were reimbursed a modest fee for participating.

To document intelligibility and speech severity, perceptual testing was completed by three certified speech-language pathologists (SLPs). All SLPs had at least 3 years of experience with dysarthria. For each speaker, 11 sentences were randomly generated using the computerized Speech Intelligibility Test (SIT; Yorkston, Beukelman, et al., 2007). Perceptual testing took place over one 2-hr session, and all testing was completed in a quiet room via binaural headphones (Sony MDR-V300 headphones). Presentation of speech stimuli was blocked by the speaker, and each SLP had a different random ordering of speakers. For every speaker, the speech intelligibility task was completed first, followed by the speech severity task. Procedures for the intelligibility task paralleled that of the SIT (Yorkston, Beukelman, et al., 2007) such that acoustic signals produced by the speakers were not altered (i.e., normalized for intensity) before presentation to the SLPs. SLPs were presented with sentences one at a time, in order from Sentence 1 to Sentence 11, and were asked to type out the words they heard. After the intelligibility task, SLPs then completed the speech severity task.

Procedures and instructions for the speech severity task were adapted from Sussman and Tjaden (2012). For this task, the same 11 sentences from the transcription task were played continuously for a given speaker, and SLPs were asked to judge overall severity, "paying attention to voice quality, resonance, articulatory precision, speech rhythm, prosody and naturalness…without focusing on how understandable or intelligible the person is." After the 11 sentences were presented, SLPs were prompted to make a single judgment of overall severity using a computerized visual analog scale (VAS). SLPs were presented with a vertical line 150 mm long and asked to click anywhere along the line ranging from "no impairment" at the bottom to "severely impaired" at the top of the scale. Ratings were converted using custom software (MMScript) onto a scale from 0 to 1.0, where 0 represents no impairment and scores closer to 1.0 represent severe impairment.

Table 1 displays the SLP-judged transcription intelligibility and scaled severity scores for each participant. Mean SIT transcription scores for the PD group and control group were 98.74% (SD = 1.43) and 97.92% (SD = 2.42), respectively. On average, the PD group (M = 0.27, SD = 0.19) was judged to have more severe speech than the control group (M = 0.17, SD = 0.16). SIT scores and scaled severity ratings demonstrate that the majority of speakers had mild dysarthria. A majority of speakers anecdotally reported developing speech difficulties after being diagnosed with PD. In addition, one third of the PD group reported receiving speech therapy postdiagnosis. Therefore, despite the lack of substantial differences in SIT intelligibility or speech severity scores between speakers with PD and control speakers, speakers with PD who participated in the current study are representative of the clinical population that may pursue speech therapy.

Data Collection

Data collection for speakers occurred over two sessions. During the first session, patient history, a cognitive screening, and the audiological screening were completed, and a clinical speech sample was obtained. During the second visit, audio recordings of experimental speech stimuli were obtained. Each session lasted between 60 and 90 min in length. The first and second sessions were separated by at least 1 hr and no more than 5 days. To minimize any potential medication effects, recording sessions for speakers with PD were scheduled 1 hr after taking anti-Parkinsonian medications.

Speakers were seated in a sound-treated booth in front of a computer screen. All speech stimuli were presented one at a time using Microsoft PowerPoint. Speakers were recorded using an over-the-ear Countryman E6IOP5L2 ISOMAX condenser microphone. A mouth-to-microphone distance of 6 cm was maintained throughout the recording session. Audio samples were recorded using the M-Audio MobilePre USB preamplifier and digitized to a computer at a sampling rate of 22 kHz using TF32 (Milenkovic, 2005) and Praat (Boersma & Weenink, 2018). Two speakers were recorded in TF32; however, due to software complications, the remainder of the recordings were completed in Praat.

Experimental Speech Stimuli

For each speaker, experimental stimuli consisted of 18 different sentences, ranging from five to 12 words selected from the SIT (Yorkston, Beukelman, et al., 2007).

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Fourteen different sentence sets were constructed for the 28 speakers. Therefore, each age- and sex-matched speaker pair (i.e., PD01 and C01) produced the same sentence set. For each speaker, the same set of experimental stimuli was recorded in four speaking conditions (i.e., habitual, SC, HI, and OE). The habitual condition was always recorded first. For the habitual condition, speakers were asked to read the sentences aloud. Six different orderings of the nonhabitual conditions (SC, HI, and OE) were randomized and blocked across speakers. In the SC condition, speakers were instructed to "say the following sentences while speaking clearly." For the HI condition, speakers were asked to "say the following sentences while speaking to someone with a hearing impairment," and for the OE condition, speakers were asked to "say the following sentences while overenunciating each word." Written instructions for each condition were presented both visually and verbally once at the beginning and midway throughout recording for each condition. Speakers were engaged in informal conversation or provided a break in between conditions to minimize carry-over effects.

In each condition, speakers were asked to provide a rating of both physical and mental speaking effort. Both physical speaking effort and mental speaking effort were judged, as prior research suggests these domains are not strongly related (Elbers et al., 2012; Friedman et al., 2007; Lou et al., 2001; Smets et al., 1995). Similar to procedures used in previous studies, a VAS was used to collect judgments of speaker-perceived effort (Roh et al., 2006; Rudner et al., 2012; Solomon, 2000; Whitehill & Wong, 2006). Each VAS consisted of a vertical line 100 mm in length anchored with text at each end. In the middle and at the end of each condition, speakers were given a paper version of each VAS and asked to place a horizontal dash anywhere along the line to indicate their response. For physical speaking effort, speakers were asked to rate "Physically, how effortful was that task?" Text at the top and bottom of the scale read "a lot of physical effort" and "very little physical effort," respectively. For mental speaking effort, speakers were asked to rate "How much were you thinking about that task?" Text at the top and bottom of the scale read "a lot of thinking" and "very little thinking," respectively. Ratings were converted into a numerical score from 0 to 10 using the distance (in millimeters) on a ruler, with 0 representing little effort and 10 representing maximal effort. Effort scores obtained in the middle of the condition and at the end of the condition were averaged to obtain mean physical speaking effort and mean mental speaking effort scores. At odds with prior studies suggesting the concepts are not associated with each other (Elbers et al., 2012; Friedman et al., 2007; Lou et al., 2001; Smets et al., 1995), physical speaking effort and mental speaking effort were found to be highly correlated in this cohort of speakers (Pearson's r = .89, 95% CI [.85, .93], $p < .001$). As such, physical speaking effort and mental speaking effort scores were averaged to obtain an overall speaking effort score for use in statistical analyses.

Perceptual Method and Procedure

Listeners. A total of 50 individuals, composed of 10 men and 40 women, with a mean age of 20 years (SD = 1.4, range: 18–40) participated as listeners. Listeners were recruited from the student population at the University at Buffalo; spoke American English as their first language; and denied a history of neurological, speech, language, or hearing pathology. Listeners reported no more than minimal experience with communication problems secondary to neurological disease or injury (i.e., listeners who had completed a course on motor speech disorders were eligible to participate). All listeners passed a bilateral hearing screening at 20 dB HL at octave frequencies between 500 and 8000 Hz, had obtained at least a high school diploma, and were paid a modest fee for participating. Listeners were blinded to the study aims, speaker diagnoses, and speaking conditions.

Perceptual Task

SLP-judged intelligibility, as indexed by the SIT, was high for all speakers (see Table 1). Thus, to prevent ceiling effects, experimental stimuli were equated for overall amplitude and mixed with multitalker babble, consistent with procedures used in other clear speech studies (Smiljanić & Bradlow, 2009). Although, per the acoustic study by Lam and Tjaden (2016), the speaker groups did not differ from each other in SPL, there were differences in SPL across conditions. Thus, to control for any effect of audibility on intelligibility judgments, sentences first were equated for average root-mean-square (RMS) intensity. To accomplish this, speech waveforms were filtered with an A-weighted filter, and levels were calculated by averaging frame-by-frame (using frame durations on the order of 10 ms) RMS sample values of nonpausal portions of the speech. Each waveform was then multiplied by an appropriate gain factor so that the resulting waveforms all had the same average RMS value. Sentences were mixed with multitalker babble sampled at 22 kHz and low-pass filtered at 11 kHz (Bochner et al., 2003; Frank & Craig, 1984). Based on pilot testing, a signal-to-noise ratio (SNR) of −1 dB was applied to each sentence, as this SNR minimized floor and ceiling effects in the intelligibility task. Sentences were presented via Sony Dynamic Stereo headphones (MDR-V300) at 75 dB. The dB level of stimuli was calibrated at the beginning of each listening session for five randomly selected experimental sentences using an earphone coupler and a Quest Electronics 1700 sound-level meter.

Each listener transcribed the 18 SIT sentences produced in one condition by each of the 28 speakers (504 sentences). In this manner, each stimulus was transcribed by 10 listeners, and a given listener only heard a particular

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SIT sentence twice (i.e., once for a PD speaker and once for a control speaker). Every listener heard a relatively equal number of conditions from each group (i.e., PD and control), and every condition for every speaker was heard by 10 different listeners.

Listeners were seated in a sound-treated booth in front of a computer. For the transcription task, listeners heard each sentence once and typed their response onto a computer using custom software. The task was self-paced, and participants followed the computer prompts to deliver each subsequent stimulus. A practice task preceded the experiment to familiarize listeners with the computer interface. Percent words correct was calculated by tabulating the number of words correctly transcribed, dividing by the number of target words, and multiplying by 100. Percent words correct was averaged across the 18 SIT sentences for each of the 10 listeners per speaker to derive an overall intelligibility score for each speaker in each condition.

Each listener also judged a random selection of about 50 stimuli (i.e., ~10% of the data) twice for the purpose of determining intralistener reliability. Reliability was calculated by summing the number of words that were transcribed the same between the first and second presentations of a given stimuli for a given listener. A ratio was calculated between the number of words that overlapped between the two presentations and the total number of words in the stimulus to obtain the percentage of overlap between the two transcriptions. The percentage of overlap for each of the 50 repeated stimuli for a given listener was averaged to obtain an overall reliability percentage per listener. Reliability percentages ranged from 46% to 81%, with an average of 64% across all listeners, which is comparable to the reliability of similar tasks (i.e., transcription of speech in noise) reported previously (Stipancic et al., 2016).

Data Analysis

Statistical analyses were completed using SAS statistical software (Version 9.4, SAS Institute Inc.) and R (R Development Core Team, 2013). To address Research Questions 1 and 2, separate linear mixed-effects (LME) models were fit to intelligibility data (Research Question 1: intelligibility across clear speech variants) and speaking effort data (Research Question 2: speaking effort across clear speech variants) in this repeated-measures design, with fixed effects of group (i.e., PD and control) and condition (i.e., habitual, SC, HI, and OE) and a random effect of speaker. For the intelligibility model, listener was also included as a random effect. Post hoc pairwise comparisons were made in conjunction with a Bonferroni correction for multiple testing. All tests were two-sided and tested at a .05 nominal significance level. To address Research Question 3, regarding the relationship between intelligibility and speaking effort, Pearson's correlations were used to assess the relationship between intelligibility and speaking effort in both groups of speakers (i.e., PD and control) and across the group of speakers as a whole.

Results

Research Question 1: Intelligibility Across Clear Speech Variants

The intelligibility LME model results are displayed in Table 2. Results revealed a significant effect of condition, $F(3, 1047) = 33.82$, $p < .001$, and a significant Group × Condition interaction, $F(3, 1047) = 11.39$, $p < .001$. There was no significant group effect, $F(1, 1047) = 2.79$, $p = .095$. Overall, there were significant differences between intelligibility in the habitual condition (M = 68.66%, SD = 16.13) and the SC (M = 73.82%, SD = 14.03, $p < .001$), HI (M = 71.37%, SD = 16.86, $p < .001$), and OE (M = 76.34%, SD = 13.14, $p < .001$) conditions. There were also significant differences in intelligibility between the SC and OE conditions ($p = .008$) and the HI and OE conditions ($p < .001$). There was no significant difference between the SC and HI conditions ($p = .46$).

Figure 1 displays boxplots of intelligibility across the four conditions for each group of speakers. Intelligibility was higher for the control group (M = 75.25%, SD = 7.92) than the PD group (M = 62.07%, SD = 19.60) only in the habitual condition ($p = .013$). For the control group, intelligibility was significantly different between the habitual condition (M = 75.25%, SD = 7.92) and the OE condition (M = 79.84%, SD = 8.61, $p = .006$), as well as between the HI (M = 75.01%, SD = 12.50, $p = .003$) and OE conditions. For the PD group, intelligibility was significantly lower for the habitual condition (M = 62.07%, SD = 19.60) as compared to the SC (M = 69.23%, SD = 17.22, $p < .001$), HI (M = 67.73%, SD = 20.13, $p < .001$), and OE (M = 72.84%, SD = 16.06, $p < .001$) conditions. For the PD group, there were also significant differences in intelligibility between the SC and OE conditions ($p = .008$) and between the HI and OE conditions ($p = .010$). No other comparisons were significant.

Table 2. Results of the linear mixed-effects model for Research Question 1: sentence intelligibility across speaking groups (Parkinson's disease and controls) and conditions (habitual, clear, hearing impaired, and overenunciate).

Effect	Num *df*	Den *df*	*F* value	*p* value
Group	1	1047	2.79	.095
Condition	3	1047	33.82	< .001
Group × Condition	3	1047	11.39	< .001

Note. Num *df* = number of degrees of freedom in the model; Den *df* = number of degrees of freedom associated with the model errors.

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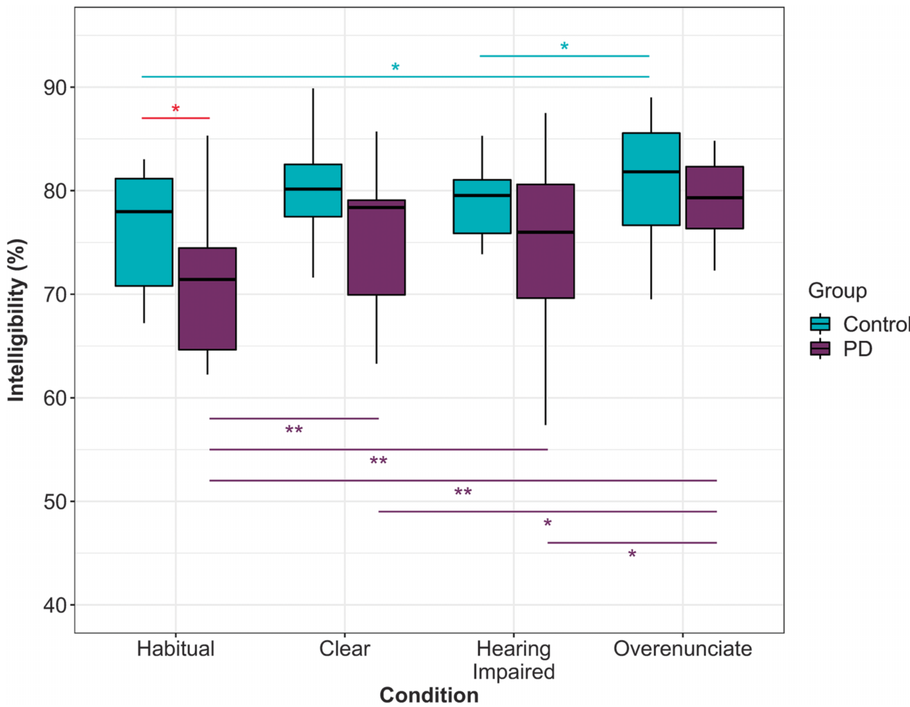
Figure 1. Percent intelligibility across the clear speech variants in the control and Parkinson's disease (PD) groups. *$p < .05$, **$p < .001$; line within each box = median, hinges = 25th and 75th percentiles, whiskers = 1.5 × interquartile range, red line = comparisons between groups, teal lines = comparisons between conditions for the control group, and purple lines = comparisons between conditions for the PD group. Note that the outliers have been removed from the figure for ease of interpretation.



Research Question 2: Speaking Effort Across Clear Speech Variants

The speaking effort LME model results are displayed in Table 3. Results revealed a significant effect of condition, $F(3, 78) = 30.67$, $p < .001$, but not a significant group effect, $F(1, 78) = 0.68$, $p = .411$, or a Group × Condition interaction, $F(3, 78) = 0.23$, $p = .877$. Speaking effort was significantly higher in the OE condition (M = 54.55, SD = 13.14) as compared to the SC condition (M = 40.52, SD = 14.03, $p < .001$) and the habitual condition (M = 28.38, SD = 16.13, $p < .001$), but not as compared to the HI condition (M = 53.27, SD = 16.86, p = 1.00). Speaking effort was also significantly different between the SC and HI conditions ($p < .001$).

Table 3. Results of the linear mixed-effects model for Research Question 2: speaking effort across speaking groups (Parkinson's disease and controls) and conditions (habitual, clear, hearing impaired, and overenunciate).

Effect	Num *df*	Den *df*	*F* value	*p* value
Group	1	78	0.68	.411
Condition	3	78	30.67	< .001
Group × Condition	3	78	0.23	.877

Note. Num *df* = number of degrees of freedom in the model; Den *df* = number of degrees of freedom associated with the model errors.

Figure 2 displays boxplots of speaking effort across the four conditions for each group of speakers. For the control group, speaking effort was significantly different between the habitual condition (M = 26.39, SD = 7.92) and both the HI condition (M = 49.89, SD = 12.50, $p < .001$) and the OE condition (M = 50.21, SD = 8.61, $p < .001$), but not the SC condition (M = 36.43, SD = 8.17, p = .319). The control group also had significantly different speaking effort scores between the SC and HI (p = .040) and OE (p = .032) conditions. No other comparisons were significant for the control group. For the PD group, speaking effort was significantly different between the habitual condition (M = 30.36, SD = 19.60) and all other conditions (SC: M = 36.43, SD = 17.22, p = .023; HI: M = 49.89, SD = 20.13, $p < .001$; OE: M = 50.21, SD = 16.06, $p < .001$). The PD group also had significant differences in speaking effort between the SC and OE conditions (p = .023). No other comparisons were significant for the PD group.

Research Question 3: Relationship Between Intelligibility and Speaking Effort

Figure 3 presents a scatter plot examining the relationship between intelligibility and speaking effort. There

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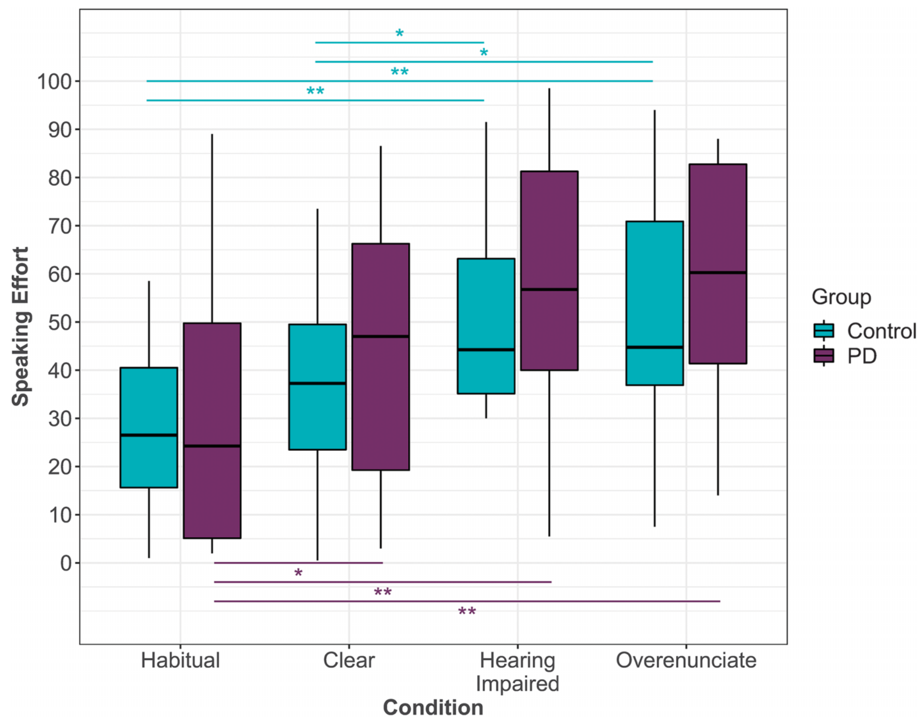
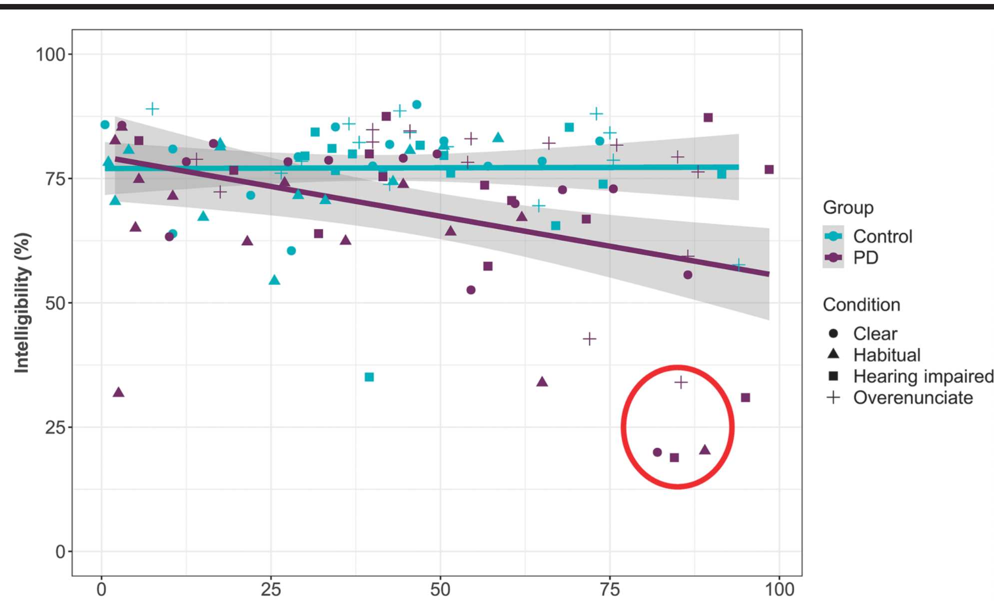
Figure 2. Speaking effort across the clear speech variants in the control and Parkinson's disease (PD) groups. *p < .05, **p < .001; line within each box = median, hinges = 25th and 75th percentiles, whiskers = 1.5 × interquartile range, teal lines = comparisons between conditions for the control group, and purple lines = comparisons between conditions for the PD group.



was a small but significant negative correlation between intelligibility and speaking effort when the two groups of participants and the four speaking conditions were pooled, $r(110) = -.29$, $p < .001$, such that as speaking effort increased, intelligibility decreased. For the control group alone, there was no relationship between intelligibility and speaking effort, $r(54) = .007$, $p = .96$. For the PD group alone, there was a significant negative

Figure 3. Relationship between intelligibility and speaking effort in the control group and Parkinson's disease (PD) group across conditions. Data points from the most severe speaker (PD14) are circled in red.



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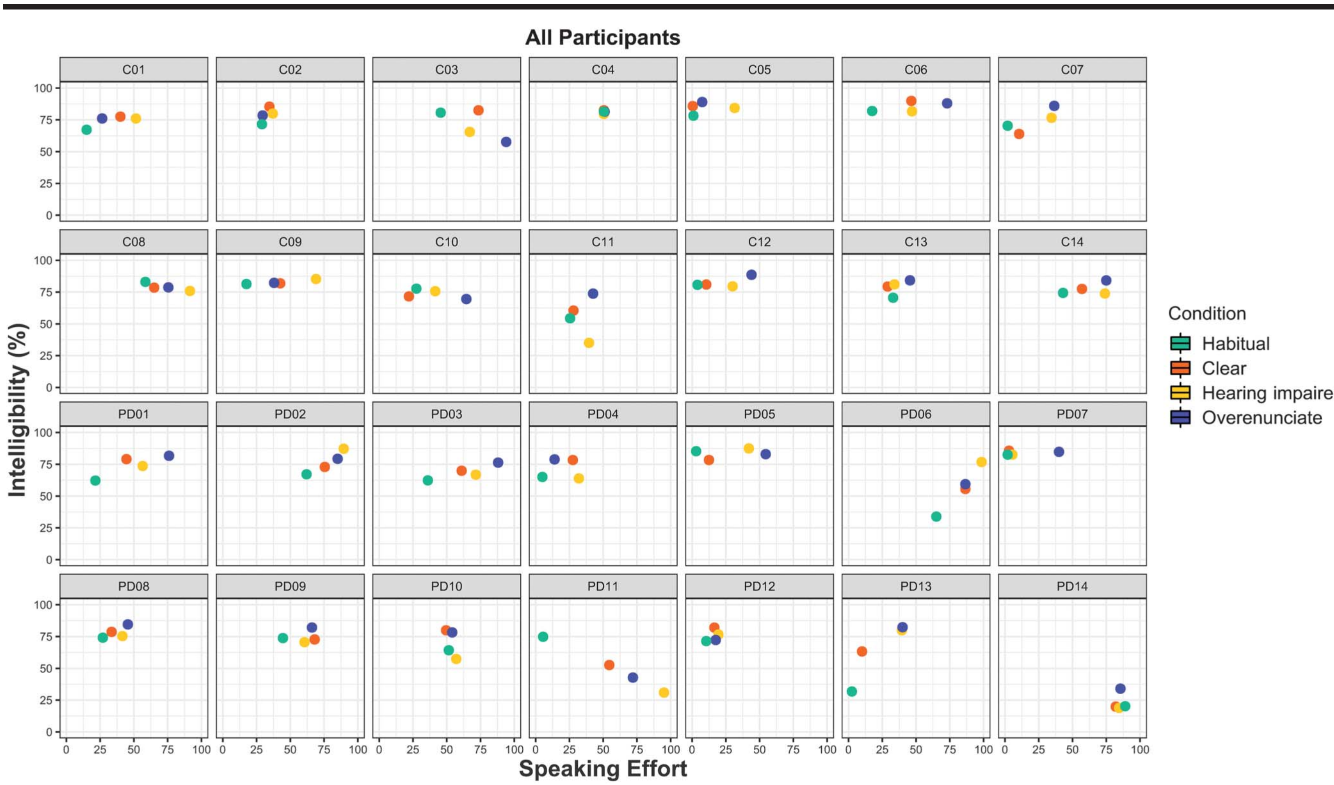
correlation between intelligibility and speaking effort, $r(54) = -.38$, $p = .004$. Upon further inspection of the data, the correlation in the PD group appeared to be driven by data for a single speaker (PD14; red circle in Figure 3) who had the lowest intelligibility and highest speaking effort scores. When this speaker was removed from the correlation analysis, the association between intelligibility and speaking effort was not significant, $r(50) = -.20$, $p = .15$.

Figure 4 illustrates the relationship between intelligibility and speaking effort within each of the 28 individual participants (similar to an approach used by Turner et al., 1995). The small number of data points precludes meaningful quantitative treatment of the data. However, visual inspection of Figure 4 reveals that, for the majority of control participants, there was either (a) a lack of variability in either measure (i.e., intelligibility or speaker effort), which is consistent with the lack of significant association between these measures in the control group, or (b) the fact that changes in one measure did not necessarily correspond to changes in the other. For example, C01, C05, C06, C08, and C10 all appear to have changes in speaking effort across the conditions that were not associated with changes in intelligibility. However, for the PD group, there are a few patterns that emerged. First, for the majority of participants (11/14, 79%), the habitual condition yielded the lowest magnitude of speaking effort, with higher speaking effort being elicited by the nonhabitual conditions. One pattern is exhibited well by PD01, PD02, PD03, PD06, PD08, and PD13, who demonstrate increased intelligibility associated with increased effort. The opposite pattern (i.e., decreased intelligibility associated with increased effort) is visible for PD11. A final pattern displayed by PD04, PD07, PD09, PD10, PD12, and PD14 resembles many control speakers, in that there is no clear association between the two measures.

Discussion

The current study sought to determine the impact of various instructions for eliciting clear speech on intelligibility and speaking effort for a group of speakers with PD and age- and sex-matched neurologically healthy controls. In addition, this study examined the relationship between intelligibility and speaking effort. Three main findings emerged: (a) Intelligibility was maximized in the OE condition, especially for speakers with PD; (b) speaking effort was highest in the OE condition; and (c) the relationship between intelligibility and speaking effort is

Figure 4. Relationship between intelligibility and speaking effort across conditions in individual participants. C = control speakers; PD = speakers with Parkinson's disease.



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complex. The following sections consider each of these findings as well as potential clinical/research implications.

Intelligibility Was Maximized in the OE Condition

Overall, the OE condition yielded the highest intelligibility gains relative to the habitual condition for both speaker groups. For the control group, intelligibility was highest in the OE condition, which was matched by intelligibility in the SC condition. For the PD group, intelligibility was statistically highest in the OE condition, as compared to each of the other three conditions (i.e., habitual, SC, and HI). Importantly, for these mildly impaired speakers with PD, all of the clear speech instructions yielded intelligibility levels that were comparable to the typical or habitual speech of age- and sex-matched controls. For the PD group, the magnitude of intelligibility gain from the habitual condition to all three clear speech conditions (i.e., SC, HI, and OE) exceeds the threshold for detectable change in intelligibility (see Stipancic & Tjaden, 2022; Stipancic et al., 2018) and thus represents meaningful changes. For speakers who have intelligibility scores ≥ 96% (as the SLP-judged intelligibility scores in Table 1 indicate for the speakers in this study), the threshold for detectable change of intelligibility has been previously reported to be ~3% (see Stipancic & Tjaden, 2022; however, it should be noted that detectable change of intelligibility obtained in the presence of background noise has not been established to date). The finding of optimized intelligibility in the OE condition also is consistent with previous work demonstrating that intelligibility was maximized for young, neurologically healthy controls given instructions to overenunciate as compared to "speak clearly" and "speak to someone with a hearing impairment" (Lam & Tjaden, 2013b).

Despite the fact that intelligibility scores derived from SLPs' transcriptions of SIT recordings in quiet were near ceiling (i.e., 98.7% for the control group and 97.9% for the PD group), intelligibility scores in the habitual condition in the presence of background noise were significantly lower for both groups (i.e., 75.25% for the control group and 62.07% for the PD group). This finding illustrates how intelligibility in quiet may not translate into intelligibility in the presence of multitalker babble. Importantly, the acoustic study by Lam and Tjaden (2016) indicated that there were no differences in SPL between these groups of speakers, providing evidence that equalizing the stimuli for SPL, and thus, audibility, did not influence current results. In addition, although SIT scores obtained from SLPs in quiet were equivalent between the control group and the PD group, the PD group had significantly worse intelligibility than the control group in the habitual condition in the presence of noise. This finding is consistent with previous work (Chiu & Forrest, 2018) and demonstrates how background noise is especially detrimental to the intelligibility of speakers with PD.

Results also suggest that although the OE condition appeared to facilitate the highest intelligibility scores *on average* in this cohort of speakers with PD, any of the instructions explored could be useful for improving intelligibility in *individual* speakers with PD. Visual inspection of Figure 4 provides additional support for this claim. For example, although many of the speakers with PD (8/14 = 57%) experienced their highest intelligibility in the OE condition, three speakers with PD (21%) experienced their highest intelligibility (or comparable to another condition) in the HI condition and five speakers with PD (36%) experienced their highest intelligibility (or comparable to another condition) in the SC condition. Importantly, only one speaker with PD (PD11) had their highest intelligibility in the habitual condition, with all clear speech variants eliciting lower intelligibility, whereas the other 13 speakers with PD all experienced an improvement in intelligibility with at least one of the clear speech variants. Therefore, although not desirable from the standpoint of efficiency, clinicians could trial various instructions for maximizing intelligibility in individual patients. For example, by combining the current findings with results in Lam and Tjaden (2016), it could be hypothesized that for speakers with PD who have predominant impairments in articulation, instructions to overenunciate may be the most beneficial for intelligibility; in contrast, for speakers with PD who have predominant impairments in suprasegmental aspects of speech, instructions used in the HI condition may be the most useful. In combination with the results in Lam and Tjaden (2016), the current results further suggest the hypothesis that change in articulation and duration are key acoustic variables explaining intelligibility change in mildly impaired speakers with PD when the effect of speech intensity is held constant. Relatedly, Gravelin and Whitfield (2019) found that speakers with PD exhibited a smaller reduction in speaking rate than control speakers under a clear speech condition elicited by the instructions "speak as clearly as possible, as if someone was having trouble hearing or understanding you." The authors posited that this may be the result of their instructions for eliciting clear speech and that instructions to overenunciate may have promoted larger articulatory adjustments in the speakers with PD (Gravelin & Whitfield, 2019).

Speaking Effort Was Highest in the OE Condition

Across all speakers, all nonhabitual speaking conditions (i.e., SC, HI, and OE) elicited larger magnitudes of speaking effort than the habitual condition. Overall, the OE condition tended to elicit the greatest ratings of effort,

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followed by the HI condition (although this contrast was not statistically significant) and the SC condition. High levels of speaking effort in the OE condition, as related to findings by Lam and Tjaden (2016) of increased vowel space area, lengthened vowel durations, and slower articulation rates in the OE condition, are consistent with the H&H theory that increased effort would be associated with greater articulatory excursions (Lindblom, 1990). Indeed, other authors have reported evidence of increased speaking effort under clear speech conditions. In a group of young, neurologically healthy controls, Whitfield et al. (2021) found that tracking accuracy in a concurrently performed visuomotor tracking task decreased when participants adopted a clear speaking style relative to when they used their habitual speech. This finding was interpreted as evidence that the adoption of a clear speaking style requires greater attentional resources than habitual speech (Whitfield et al., 2021). These findings are consistent with the current findings in that use of a clear speaking style yielded higher levels of perceived effort. Keerstock and Smiljanić (2021) also provided evidence that a clear speaking style requires more effort on the part of the speaker than habitual speech. Their results indicated that a speaker's recall of their own speech was worse for sentences produced using a clear speaking style than for sentences produced in conversational speech. The authors suggested that this finding was due to the increased effort required by the clear speech task (elicited by the instructions "Read this sentence clearly and carefully, as if talking to a non-native speaker of English or a person with hearing loss," pp. 3389–3390). Authors suggested that the clear speech task was "resource demanding" (p. 3395), and thus, diverted cognitive resources necessary to successfully complete the memory task (Keerstock & Smiljanić, 2021). In contrast, when listeners are asked to recall speech produced by others, they experience a memory/recall benefit for speech produced in a clear speaking style (Gilbert et al., 2014; Keerstock & Smiljanić, 2018, 2019; Van Engen et al., 2012). This speaker–listener dichotomy in benefits derived from a clear speaking style highlights the value of selecting and evaluating the suitability of treatment approaches from the perspective of both the speaker and the listener. For example, when evaluating the costs of a motor behavior, or speech in particular (Cos, 2017; Morel et al., 2017; Whitfield et al., 2021), it should be established from whose perspective the cost is determined (i.e., speaker vs. listener; Olmstead et al., 2020).

Similar to intelligibility findings, individual speakers' judgments of perceived effort varied across the clear speech instructions. Half of the control speakers (50%) and six of the PD speakers (43%) reported the highest values of speaking effort in the OE condition, whereas five of the control speakers (38%) and four of the PD speakers (29%) reported the highest values of speaker effort in the HI condition (see Figure 4). Interestingly, PD14, who had the lowest intelligibility score of all speakers in the habitual condition (and, therefore, was the most severely impaired; see Stipancic et al., 2021), reported constant levels of speaking effort across all of the speaking conditions, including the habitual condition. This suggests a ceiling effect in which this participant was already working at the limit of their physiologic, functional reserve (Plowman, 2015) when using their typical speaking pattern.

The Relationship Between Intelligibility and Speaking Effort Is Complex

Overall, speakers with PD did not judge implementing variants of clear speech instruction to be significantly more effortful than the control group, as evidenced by a nonsignificant group effect in the LME model for speaking effort. In addition, for the control group, there was no relationship between intelligibility and speaking effort, despite a large range of speaking effort scores (as shown in Figures 3 and 4). We hypothesize that the lack of relationship between intelligibility and speaking effort represents a ceiling effect, as controls were highly intelligible across all conditions. There was, however, a statistically significant, negative relationship between intelligibility and speaking effort for the PD group, indicating that as speaking effort increased, intelligibility decreased. This negative relationship appeared to be largely driven by the most severely impaired speaker (i.e., PD14), with the lowest intelligibility scores, and therefore, future work with a larger sample size is needed to corroborate these findings. Examining the relationship between intelligibility and speaking effort within individual participants revealed more nuanced patterns (see Figure 4). For example, some participants with PD (8/14 = 57%; PD01, PD02, PD04, PD05, PD06, PD08, PD09, PD13) showed a clear increase in intelligibility that coincided with an increase in speaking effort. This pattern is consistent with the H&H theory (Lindblom, 1990) in that greater effort facilitates increased acoustic contrasts at the hyperarticulate end of the continuum, resulting in improved intelligibility. In contrast, one speaker with PD (i.e., PD11) exhibited the exact opposite relationship, as intelligibility declined with increases in speaking effort. Interestingly, the negative relationship between intelligibility and speaking effort for PD11 was not predicted by overall dysarthria severity, as may be hypothesized. PD11 had similar intelligibility in the habitual condition to many other speakers with PD who demonstrated a positive relationship between intelligibility and speaking effort. A few authors in the rehabilitation sciences literature have noted this dissociation between effort and performance, such that increased effort can be unproductive for improving motor performance (see Bruya,

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2010, for a review) or that what is most important is the *type* of effort that is being expended (see Hodges & Lohse, 2020, for a review). Future work should explore predictors of the relationship between effort and motor performance, particularly as it relates to speech production.

Although the motor execution–effort relationship has received much more attention in the limb literature as compared to the speech literature, the relationship between motor execution and effort is, nevertheless, not well defined in the limb literature. Generally, novel motor skills are thought to be associated with a requirement for increased effort, whereas skilled movements tend to be associated with less effort, automaticity, and high efficiency (see Bruya, 2010; Hodges & Lohse, 2020; Sparrow, 1983; Wulf & Lewthwaite, 2016, for reviews). Therefore, clinically, maintaining an intelligibility benefit while also reducing the amount of effort perceived by the patient may be a relevant goal. As such, speaking effort may be a relevant outcome measure for determining treatment efficacy. For example, in treatments aiming to improve intelligibility, it may be beneficial to observe a decrease in effort over time while maintaining intelligibility (Richardson et al., 2022). Subjective measures of effort could serve as a proxy for task automaticity over time (Whyte et al., 2019). For example, a recent study examined physical and mental demand of patients with PD during two interventions aimed at increasing vocal loudness. In this study, Richardson et al. (2022) suggested that changes in measures of physical and mental demand may reflect differences in "treatment burden" (pp. 10, 11). In particular, the authors found that, for one of the voice treatments, ratings of physical effort declined over time while performance improved, which was hypothesized to be the result of treatment-related motor adaptation and/or physical muscle conditioning (Richardson et al., 2022). Relatedly, the physical therapy literature suggests that there may be a level of effort that is optimal for motor learning and performance (see Bruya, 2010; Hodges & Lohse, 2020, for reviews). Therefore, there may be a range of speaking effort that is advantageous for producing the most intelligible speech or for facilitating optimized learning of a new speaking style. Further research on this topic is warranted.

The approach illustrated in Figure 4 may be useful for determining the optimal instructions for eliciting clear speech in an individual patient. As an example, the figure shows that PD01 was 60% intelligible in the habitual condition and experienced the largest intelligibility gain under the OE condition (78.6% intelligibility, a difference of 18.6%). However, the OE condition elicited the highest amount of speaking effort (a score of 76 as compared to a score of 21.5 in the habitual condition). Perhaps, in this case, the SC speaking condition, which still yielded a large, clinically significant improvement in intelligibility (77.5% intelligibility, a difference of 17.5% from the habitual condition) but a smaller increase in speaking effort (a score of 44.5 as compared to 21.5 in the habitual condition), may be more sustainable. Another possibility is that a clinician could select the OE condition for this speaker but monitor perceived speaking effort over therapy sessions to assess the sustainability of the newly adopted speaking style. If, for example, effort remains at a high level, trialing an alternative, less effortful speaking style may be appropriate. This begs the question: How much effort is too much effort? If, for example, a speaking condition maximizes intelligibility but also requires the greatest amount of effort (as in the current findings under the OE condition), it is important to evaluate a speaker's willingness to invest the additional effort required to achieve high intelligibility and the effect that this has on adherence to therapy/use of the speaking style. Conversations with patients regarding anticipated outcomes (i.e., increased intelligibility vs. high amounts of effort) may be a good starting point. This discussion is related to the concepts of economy of effort and the cost versus utility of motor behaviors. Especially for patients with PD who experience heightened levels of fatigue and effort at baseline, the costs associated with high-effort therapy tasks may result in an undervaluation of an intelligibility benefit and the abandonment (or effort economization) of a particular speaking style. These factors are critical to determining therapeutic efficacy in this population. The interaction of intelligibility and speaking effort and their combined effect on therapy adherence require additional research in the future.

Limitations and Future Directions

Some researchers have noted that speakers with PD have sensory perceptual difficulties (Fox & Ramig, 1997; Ho et al., 2000; Sapir et al., 2011), which could, theoretically, impact subjective impressions of speaking effort. However, speakers with PD in the current study had perceived physical and mental speaking effort comparable to controls, which may suggest that speakers with PD did not have difficulty with rating effort. Although sensory perceptual deficits are important to consider when studying the PD population, it is beyond the scope of the current work and should be considered in future studies.

To date, no standardized definitions or metrics of "clear speech effort" or "speaking effort" have been established. Therefore, further research is needed to determine the reliability and validity of the VAS ratings used to capture speaking effort during clear speech. In the current study, reliability of the speaking effort measures was not obtained. Reliability of these measures will be important for work establishing thresholds for a clinically detectable and significant change (see Stipancic & Tjaden, 2022;

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Stipancic et al., 2018). Future work could examine variability in perceived effort as related to variability in intelligibility across longer speech materials (similar to the work by van Brenk et al., 2022) to better define the relationship between speaking effort and sustainability of a speaking style.

Last, the methods utilized in this study (e.g., highly controlled acoustic recordings of sentences read aloud, lab listening conditions) are not representative of natural communication. Studies are needed to determine the effect of different speaking conditions on intelligibility and speaker effort in more ecologically valid settings. Future work should also consider other factors that impact the sustainability of behavioral speech protocols, such as attention (Whitfield et al., 2021; Wulf & Lewthwaite, 2016), memory (Keerstock & Smiljanić, 2021), fatigue (Friedman et al., 2007; Marr, 1991), and motivation (Maclean & Pound, 2000; Wulf & Lewthwaite, 2016), as well as using speaker effort as a supplement to listener-derived speech outcomes (i.e., intelligibility). These factors will be relevant for appraising the cost of behavioral therapies from the perspective of speakers and will be useful for examining the sustainability of therapies in the long term. Overall, the current results suggest that future work should consider standardizing the instructions used to elicit clear speech, as variability in instructions limits the ability to compare outcomes across studies. Last, current findings highlight the importance of considering instruction when making direct comparisons between clear speech studies.

Data Availability Statement

Data supporting the results reported in this article are available for interested researchers on request from the authors.

Acknowledgments

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