Listener Ratings of Effort, Speech Intelligibility, and Loudness of Individuals with Parkinson's Disease and Hypophonia

Évaluation de l'effort, de l'intelligibilité de la parole et de l'intensité vocale des personnes atteintes de la maladie de Parkinson et ayant une hypophonie

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KEYWORDS

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Abstract

Hypophonia is a speech deficit observed in hypokinetic dysarthria associated with Parkinson's disease. This study investigated how multi-talker background noise affects listener ratings of effort, sentence intelligibility, and perceived speech loudness of individuals with Parkinson's disease and hypophonia and explored potential relationships among these variables. Ten individuals (8 women, 2 men; 18–43 years of age [M = 24.1; SD = 6.89]) were recruited as listener participants. Speech stimuli were obtained from audio recordings of 22 adults (17 men, 5 women; 58–80 years of age [M = 69.41, SD = 6.91]) with Parkinson's disease and hypophonia. These audio recordings were comprised of 13- to 15-word sentences from the Sentence Intelligibility Test (Yorkston, Beukelman, & Tice, 2011) read aloud in no added background noise and in 65-decibel multi-talker background noise. Listeners rated the intelligibility of the sentences using orthographic transcription, then rated the "perceived effort" expended when transcribing the sentences on a 100mm visual analogue scale. Listeners also rated the perceived loudness of the speakers with Parkinson's disease using a visual analogue scale. Paired samples t tests ($p < .05$) compared ratings of listener effort, sentence intelligibility, and ratings of perceived loudness across the two background noise conditions. Pearson correlational analyses determined the degree of correlation among listener effort scores, intelligibility scores, and perceived loudness ratings. Individuals with Parkinson's disease and hypophonia were rated to have less intense speech and reduced sentence intelligibility, and listeners reported significantly higher ratings of effort in background noise.

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Abrégé

L'hypophonie est une caractéristique de parole de la dysarthrie hypokinétique, qui est associée à la maladie de Parkinson. La présente étude a examiné la façon dont un bruit de fond où plusieurs interlocuteurs parlaient affectait l'évaluation de l'effort et de l'intelligibilité des phrases, ainsi que l'évaluation de la perception de l'intensité de la parole des personnes atteintes de la maladie de Parkinson et ayant une hypophonie. Cette étude a également exploré les relations potentielles entre les variables mentionnées ci-haut. Dix individus (8 femmes, 2 hommes), âgés entre 18 et 43 ans (M = 24,1; ET = 6,89), ont été recrutés à titre de participants « auditeurs ». Les stimuli de parole ont été obtenus à partir d'enregistrements audio de 22 adultes (17 hommes, 5 femmes), âgés entre 58 et 80 ans (M = 69,41, ET = 6,91). Ceux-ci étaient tous atteints de la maladie de Parkinson et avaient une hypophonie. Ces enregistrements audio comprenaient des phrases composées de 13 à 15 mots tirées du *Sentence Intelligibility Test* (Yorkston, Beukelman et Tice, 2011). Les phrases étaient lues à haute voix dans deux conditions : la première n'avait aucun bruit de fond et la deuxième avait un bruit de fond (où plusieurs interlocuteurs parlaient) de 65 décibels. Les participants « auditeurs » ont évalué l'intelligibilité des phrases à l'aide d'une transcription orthographique, puis ils ont évalué l'effort qu'ils ont déployé à transcrire les phrases sur une échelle visuelle analogique de 100 mm. Les participants « auditeurs » ont également évalué l'intensité vocale des individus atteints de la maladie de Parkinson à l'aide d'une échelle visuelle analogique. Des tests t pour échantillons appariés (p < 0,05) ont été utilisés pour comparer, entre les deux conditions de bruit de fond, les évaluations de l'effort déployé par les auditeurs, ainsi que les évaluations de l'intelligibilité des phrases et de la perception de l'intensité vocale. Des analyses corrélationnelles (Pearson) ont été utilisées pour déterminer le degré de corrélation entre les scores d'effort de l'auditeur, les scores d'intelligibilité de la parole et les évaluations de la perception de l'intensité vocale. Les évaluations effectuées montrent que l'intensité de la parole et l'intelligibilité des phrases des individus atteints de la maladie de Parkinson et ayant une hypophonie sont réduites et que l'effort devant être déployé par les participants « auditeurs » est significativement plus élevé dans la condition avec un bruit de fond.

Hypokinetic Dysarthria

It is estimated that over 75% of individuals with Parkinson's disease (PD) may experience speech and voice irregularities, referred to as hypokinetic dysarthria (Adams & Jog, 2009; Logemann, Fisher, Boshes, & Blonsky, 1978; Skodda, 2011) that can be related to disease progression. Speech and voice symptoms of hypokinetic dysarthria include short rushes of speech, inappropriate silences, variable rate, reduced stress, monopitch, monoloudness, harsh voice, breathy voice, and reduced loudness (Darley, Aronson, & Brown, 1975; Duffy, 2013). Hypokinetic dysarthria is generally associated with reduced overall movement in the orofacial regions. This can present as speech-related movements that are abnormally reduced in size and force (Adams & Dykstra, 2009; Duffy, 2013; Rusz, Cmejla, & Tykalova, 2013). Due to this reduction, articulation, speech intensity, and prosody can all seem to be attenuated (Adams & Dykstra, 2009).

One of the most prevalent and distinctive speech symptoms of hypokinetic dysarthria is hypophonia, also referred to as low speech intensity. This speech symptom can decrease speech intelligibility and hinder verbal communication in a multitude of social contexts (Darley et al., 1975). According to Gamboa et al. (1997) and Ludlow and Bassich (1984), 42% to 49% of individuals with hypokinetic dysarthria present with hypophonia. Generally, when asked to speak louder individuals with hypophonia are able to increase their speech intensity, but indicate that they feel they are speaking at an inappropriately loud level (Clark, Adams, Dykstra, Moodie, & Jog, 2014). Previous studies have demonstrated reduced loudness in people with PD (Illes, Metter, Hanson, & Iritani, 1988) and reduced speech intensity in conversation (Dykstra, Adams, & Jog, 2012b; Ho, Iansek, & Bradshaw, 1999; Moon, 2005). Often there is a dichotomy between clinical and perceptual impressions of hypophonia and the failure of measures to capture this phenomenon. For example, in clinical settings individuals with PD may seem appropriately loud due to the lack of background noise or they may increase their speech intensity because they know what is expected of them in a treatment setting (Dykstra, Adams, & Jog, 2012a, Dykstra, Hakel, & Adams, 2007).

It is typical for researchers to measure speech intensity in reading tasks (e.g., Canter, 1963) and in repetition or imitation of sentences tasks (e.g., Ludlow & Bassich, 1984). However, significant differences in speech intensity were not found between control participants and individuals with PD in these studies. Studies that use conversational tasks have been able to demonstrate reduced speech intensity in individuals with PD (e.g., Dykstra et al., 2012b; Fox & Ramig, 1997; Ho et al., 1999; Moon, 2005). Adams et al. (2006) and Adams, Haralabous, Dykstra, Abrams, and Jog (2005) have also demonstrated that under a variety of background noise conditions, individuals with hypophonia and PD have reduced speech intensity. Indeed, individuals with hypophonia and PD have been found to have lower speech intensity levels than controls by 2–5 dB SPL (Adams et al., 2006; Fox & Ramig, 1997; Ho et al., 1999; Leszcz, 2012).

Speech Intelligibility

Deficits in speech intensity regulation can contribute to reductions in the speech intelligibility of individuals with hypokinetic dysarthria (Adams et al., 2005, 2006; Adams, Dykstra, Jenkins, & Jog, 2008). Speech intelligibility is based on a combination of articulatory, respiratory, laryngeal, velopharyngeal, and prosodic aspects of speech production (Dykstra et al., 2007). Speech intelligibility tests tend to focus on single word or sentence intelligibility and these tests are typically administered in quiet testing conditions. Due to this, the speech intelligibility of individuals with PD can appear relatively unimpaired when intelligibility tests are administered in quiet conditions compared to in background noise (Dykstra et al., 2012a).

Further, hypophonia is most evident in conversational speech tasks (Fox & Ramig, 1997; Ho et al., 1999). Conversation does not always occur in quiet environments, but rather in naturalistic communicative conditions where differing levels of noise are present, such as speaking in a noisy restaurant or while travelling in a car. Previous studies have explored the conversational intelligibility of individuals with PD and hypophonia in various intensities of multi-talker background noise (Adams et al., 2006, 2008; Dykstra, 2007; Dykstra et al., 2012a). In general, these studies have demonstrated that individuals with hypophonia have reduced speech intelligibility in conversation compared to control participants, despite relatively unimpaired speech intelligibility in quiet testing conditions (Adams et al., 2008; Dykstra et al., 2012a). Further, without the addition of background noise, Dykstra et al. (2012b) found more variability in speech intensity but no significant difference in the intelligibility scores of individuals with PD versus control participants.

Lombard Effect

Introducing background noise when studying hypophonia in PD provides a relevant context because background noise can exacerbate the effect of reduced speech intensity (Dykstra et al., 2012b). When individuals are speaking in the presence of noise, there is an unconscious increase in their vocal intensity in order to be heard over the noise. This phenomenon is referred to as the Lombard effect (Lane & Tranel, 1971). The Lombard effect can be used to help gain an understanding of the relationship between background noise and speech intensity in all speakers and listeners. The Lombard effect is a listener-centred phenomenon because it serves to ensure that the listener hears the correct message from the speaker as background noise increases (Amazi & Garber, 1982; Dykstra et al., 2012b; Lane & Tranel, 1971). Therefore, speakers increase their speech intensity in noise because there is a premium on intelligible communication (Lane & Tranel, 1971). In background noise, individuals without PD will increase the duration, intensity, and fundamental frequency of their speech, specifically for informationally important words, in order to get the correct message across (Patel & Schell, 2008). The difficulty to be heard and understood over noise that individuals without PD face when speaking in background noise is assumed to be exacerbated for individuals with hypophonia (Adams et al., 2005). Studying the Lombard effect in individuals with hypophonia and PD can provide researchers with important information about the nature of this condition.

Under a variety of background noise conditions, individuals with hypophonia and PD have been found to have reduced speech intensity (Adams et al., 2005, 2006). For example, Leszcz (2012) found that control participants had a mean intensity of 71.05 dB SPL and participants with PD and hypophonia had a mean intensity of 66.87 dB SPL while reading sentences derived from the Sentence Intelligibility Test (SIT; Yorkston, Beukelman, & Tice, 2011) in no background noise. In 65 dB SPL background noise, control participants had a mean intensity of 72.25 dB SPL and participants with PD and hypophonia had a mean intensity of 69.36 dB SPL while reading sentences derived from the SIT (Yorkston et al., 2011; see also Leszcz, 2012). To avoid floor or ceiling effects in terms of speech intensity, background noise should be between 50 and 90 dB SPL to elicit the Lombard effect, and these levels are comparable to communicative situations individuals may encounter everyday (Adams et al., 2005; Dykstra et al., 2012b; Lane & Tranel, 1971). Previous studies that examined speech intensity regulation levels have found that, in general, individuals with hypophonia and PD have speech intensity levels that are 2–5 dB SPL less intense than control participants, even when speaking in background noise (Adams & Dykstra, 2009; Adams et al., 2005, 2006; Dykstra et al., 2012b; Fox & Ramig, 1997; Ho, Bradshaw, & Iansek, 2000; Leszcz, 2012). Thus, while individuals with PD do demonstrate a Lombard effect, their speech is consistently less intense than control participants (Adams et al., 2006; Dykstra et al., 2012b; Stathopoulos et al., 2014). Together these studies suggest that individuals with PD and hypophonia have reduced speech intensity relative to healthy control participants and demonstrate a similar pattern of speech intensity regulation but with an attenuated pattern of response (i.e., an overall reduction in gain for speech intensity) in background noise (Dykstra et al., 2012b).

Listener Effort

During speech production, various speech parameters (i.e., articulatory precision, rate of speech, prosody, voice quality, speech intensity) can differentially affect how well a message is understood by impacting speech intelligibility. Intelligibility in dysarthria has previously been discussed within the context of the conceptual framework of the International Classification of Functioning, Disability, and Health (World Health Organization, 2001; see Dykstra et al., 2007). In addition to affecting speech intelligibility, these speech parameters, when disordered, may also contribute to increased listener effort (Duffy, 2013). There is empirical literature suggesting that listeners need to exert an increased amount of effort when listening to dysarthric speech (e.g., Dykstra, 2007; Landa et al., 2014; Whitehill & Wong, 2006). This increased effort can cause a breakdown or a barrier to communication because listeners may be forced to reallocate cognitive and attentional resources. Also, it may reduce opportunities for people with dysarthria to communicate, thereby impacting the Participation domain of the International Classification of Functioning, Disability, and Health framework (Dykstra et al., 2007; Yorkston, Klasner, & Swanson, 2001). Participation refers to the involvement in life situations (World Health Organization, 2001). Eadie et al. (2006) extended the definition of Participation to include communication and termed it *Communicative Participation*, which is defined as "taking part in life situations where knowledge, information, ideas, or feelings are exchanged. It may take the form of speaking, listening, reading, writing, or nonverbal means of communication" (p. 309).

Landa et al. (2014) demonstrated that when listeners rated "ease of listening" for dysarthric speech, poorer speech intelligibility scores were associated with increased listening effort. Transcription based speech intelligibility tests serve to identify the percentage of words correctly understood by a listener (i.e., SIT; Yorkston et al., 2011). However, intelligibility tests do not provide information on the perceptual load experienced by a listener when transcribing a disordered speech signal, and similar intelligibility scores could be obtained at the expense of unequal resources allocated by the listener (Beukelman et al., 2011). Evaluating the perceived effort of listeners is an important aspect to examine in addition to speech intelligibility, especially in noise. For example, Beukelman et al. (2011) provided a poignant example that family members often report working very "hard" to understand the speech of an individual, despite relatively high perceptual ratings of speech intelligibility. Evaluating how listeners perceive effort has the potential to add to our knowledge of the impact of dysarthria from a holistic perspective. By understanding how hypophonia in PD impacts listener effort in background noise it is possible to explore how communicative participation is impacted in the speaker–listener communicative dyad.

Current Study

Hypophonia is a common symptom of PD that requires treatment (Adams et al., 2005). The introduction of background noise is a particularly relevant context to study hypophonia and its effect on speech intelligibility, ratings of listener effort, and ratings of perceived speech loudness because most communication occurs with some degree of background noise (e.g., speaking in noisy environments, travelling in a car). The impact of hypophonia on communication is often observed to be exacerbated by the intensity of the surrounding background noise. In general, the introduction of background noise creates communication difficulties not only for the person with hypophonia, but also creates challenges for communication partners to receive messages intelligibly from the speaker with PD. Unfortunately, little is known about how background noise affects both listener ratings and relationships among sentence intelligibility, ratings of effort, and ratings of perceived speech loudness of individuals with hypophonia and PD. Studying these variables and defining the relationships among them does not only have important implications for our understanding of hypophonia and its impact but can help to provide contextually relevant assessment and treatment.

The purpose of this study was to investigate how two different background noise conditions, (a) no added background noise and (b) 65 dB SPL multi-talker background noise, affect ratings of sentence intelligibility, listener effort, and perceived speech loudness of speakers with PD and hypophonia. This study also explored potential relationships among ratings of sentence intelligibility, listener effort, and perceived speech loudness in the two background noise conditions.

In both a no added background noise condition and a 65 dB SPL multi-talker background noise condition, the following objectives were addressed: (a) evaluate and compare ratings of perceived speech loudness with acoustic speech intensity data; (b) evaluate and compare transcription based sentence intelligibility scores, ratings of listener effort, and ratings of perceived speech loudness; (c) determine the relationship between sentence intelligibility and ratings of listener effort; (d) examine the strength of the relationship between ratings of listener effort and perceived speech loudness; and (e) examine the strength of the relationship between ratings of sentence intelligibility and perceived speech loudness.

Method

Participants

This study included the recruitment of 10 listener participants, consisting of 2 men and 8 women, 18–43 years of age (M = 24.1, SD = 6.89). All listeners spoke English as a first language; had no speech, hearing, or neurological impairments; and did not have extensive research or clinical experience with dysarthric speech or Parkinson's disease. All listeners passed a 25 dB HL hearing screening bilaterally at 500, 1000, 2000, and 4000 Hz before participating. This study received approval from Western University's Research Ethics Review Board (IRB 00000940).

Speech Stimuli

Speech stimuli were obtained from audio recordings of 22 adults (17 men, 5 women; age range: 58–80 years, M = 69.41, SD = 6.91) diagnosed with PD and hypophonia as their primary dysarthric symptom. The audio recordings consisted of 13- to 15-word sentences taken from the SIT (Yorkston et al., 2011). The SIT is comprised of a list of 11 sentences that can be randomly selected. Sentences range in length from 5–15 words. In the present study, only sentences 13–15 words long were used to determine speech intelligibility and to rate listener effort. Sentences were read aloud in no added background noise and in 65 dB SPL of multi-talker background noise. All speakers with PD were fluent in English (written and spoken), able to read sentences from a piece of paper, and diagnosed with PD and hypokinetic dysarthria. **Table 1** contains specific data for each speaker with PD at the time the audio recordings were made. This table includes information about the speaker's sex, age, and years since diagnosis.

Recording task and noise conditions. The speech recordings of speakers with PD were originally recorded in a no added background noise condition and a 65 dB SPL multi-talker background noise condition which is described below. Each speaker with PD read aloud a randomly generated list of sentences unique from that of the other speakers. No two speakers received identical lists of sentences. Different sentences were read aloud by each

Table 1

Demographic Information of Speakers with Parkinson's Disease (PD)

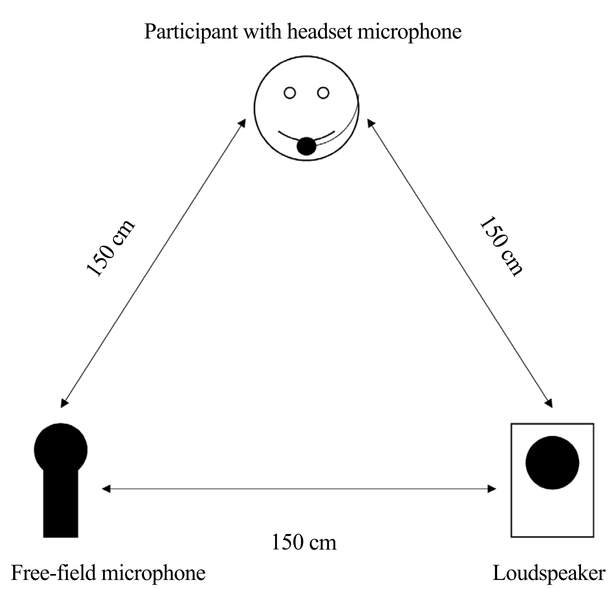
ID of speakers with PD	Sex	Age	Years since diagnosis
PD1	M	59	12
PD2	F	70	5
PD3	M	79	1
PD4	M	74	14
PD5	F	76	16
PD6	F	72	7
PD7	F	74	3
PD8	F	67	9
PD9	M	73	15
PD10	M	58	1
PD11	M	63	5
PD12	M	62	16
PD13	M	74	16
PD14	M	73	5
PD15	M	67	2
PD16	M	75	2
PD17	M	80	1
PD18	M	59	1
PD19	M	78	4
PD20	M	60	5
PD21	M	67	6
PD22	M	67	3

speaker with PD in the two background noise conditions. Each speaker with PD was instructed to read aloud 11 sentences that were 13–15 words in length from the SIT and were presented on a standard 8½ by 11-inch piece of white paper in 18-point Times New Roman font.

For both noise conditions, speakers with PD were tested in an audiometric soundproof booth (Industrial Acoustic Company). In the no added background noise condition, there was no background noise added to the room when speakers with PD read sentences from the SIT. In the 65 dB multi-talker background noise condition, a loudspeaker presented free-field multi-talker noise (Audiotech – 4 talker noise) calibrated at 65 dB SPL while each speaker with PD read sentences from the SIT.

With the examiner present in the room, the speaker with PD, a boom-mounted floor microphone (Shure SM48), and a loudspeaker were situated in an equilateral triangle, 150 centimetres (cm) away from each other (**Figure 1**). The original examiner (S. A.) adjusted the sound level (dB SPL level) of multi-talker noise via a diagnostic audiometer (GSI 10) located within the audiometric booth. The speakers with PD wore a headset microphone (AKG-C420) to record their utterances. For both conditions, the headset microphone served as the primary source for obtaining measures of speech intensity. The boom-mounted microphone was placed on a support boom at a height of 100 cm from the floor (150 cm from the speaker's mouth), and this microphone served as the primary source for obtaining listener ratings of speech intelligibility, effort, and loudness. The boom-mounted microphone was calibrated by a free-field 1000 Hz tone and a sample of the multi-talker noise was presented at 70 dB SPL from the loudspeaker (150 cm away). The recordings were made by attaching the boom-mounted floor microphone and headset microphone to a USB pre-amplifier system (M-Audio; Pre-Mobile USB system) via dual XLR connectors. The USB pre-amplifier was then attached to a laptop computer via a USB port. The laptop had the audio recorder software associated with Praat (version 5.2.14; Boersma & Weenink, 2011) installed, and the speech analysis program digitized the dual (stereo) microphone acoustic signals at 44.1 kHz and 16 bits per channel.

Figure 1



Experimental setup.

Speech intensity. Speech intensity measures were collected for each speaker with PD in the no added background noise and 65 dB SPL multi-talker background noise conditions. The speech intensity values were measured using Praat (version 5.4.04; Boersma & Weenink, 2013). Speech intensity measures were obtained by taking an average of the speech intensity between onset and offset of voicing, and then calculating an average across the three sentences for each speaker with PD in each noise condition. All speech intensity measures were based on the headset microphone recordings calibrated using a sound level meter to a 65 dB reference intensity signal that was 15 cm from the speaker's mouth.

Speech sample editing. Audio-recorded speech samples were compiled into playlists for each of the two listening sessions in the open-source program Praat (version 5.4.04; Boersma & Weenink, 2013). Each audio-recorded speech sample was comprised of three sentences (13, 14, and 15 words in length) from the SIT (Yorkston et al., 2011). With 22 PD speech samples and the samples from four randomly selected speakers with PD repeated within each playlist for determination of intra-listener reliability, the playlists were 26 samples long, with 4-second pauses between sentences. The order of presentation of the sentences was randomized so that there were five orders for each condition (i.e., no added background noise and 65 dB). This allowed for inter-rater reliability since two different listeners heard each playlist.

Listening Task

Listener participants completed the listening protocol individually over two 1.5–2 hour listening sessions. Participants completed ratings in the no added background noise condition during one session and in the 65 dB multi-talker background noise condition during the other session. The order of which noise condition was presented first was counterbalanced so that half of the participants listened to the no added background condition first, and the other half listened to the 65 dB multi-talker background noise condition first. While seated in a quiet laboratory, all participants listened to audio-recorded speech stimuli through AV 40 (M-Audio) speakers connected to a Sony Vaio laptop. Listeners were asked to rate speech intelligibility using orthographic transcription and make judgments of effort using visual analogue scaling. Finally, listeners rated the perceived speech loudness of the speech stimuli, using visual analogue scaling. This procedure was repeated for each of the 22 speakers with PD based on their audio recordings of three sentences from the SIT. The details of each task are presented below.

Speech intelligibility. During the entire listening protocol, listeners were seated 61 cm from two M-audio speakers, which were fixed at a predetermined volume of 65 dB SPL. The examiner, with the use of a multi-talker noise calibration file, predetermined the intensity level to 65 dB. Listeners rated speech intelligibility based on 13- to 15-word sentences using the scoring procedures outlined in the SIT (Yorkston et al., 2011). Listeners orthographically transcribed audio recordings of the three sentences from the SIT (Yorkston et al., 2011) in the two background noise conditions. An intelligibility score was calculated by comparing transcribed words and sentences to the stimuli on the master list.

Listener effort rating. Directly following the orthographic transcription task, listeners indicated the amount of "perceived effort" they expended when orthographically transcribing the three spoken sentences in either the no added background noise condition or the 65 dB SPL multi-talker background noise condition. This effort judgment was rated on a 100mm visual analogue scale with the anchors *no effort required* and *maximum effort required*.

Speech loudness severity rating. Listeners were presented with the audio-recorded PD speech samples again (i.e., three spoken sentences). Listeners were asked to rate their perception of reduced speech loudness using visual analogue scaling based on severity. The anchors on the 100mm visual analogue scale corresponded to *normal* and *severely abnormal/impaired*.

Data Analysis

An alpha level of $p = .05$ was used for all statistical analyses. Pearson correlational analyses determined the degree of correlation between perceived speech loudness ratings and acoustic speech intensity data in both noise conditions. Three paired samples *t* tests compared ratings of sentence intelligibility, listener effort, and perceived speech loudness in the two background noise conditions. Pearson correlational analyses determined the degree of correlation among sentence intelligibility scores, listener effort scores, and perceived speech loudness ratings across both noise conditions.

Results

Statistical Power

Statistical power is based on a relationship between sample size, variance in the data, effect size, and statistical significance (Portney & Watkins, 2000). Power reflects the ability to detect treatment differences and the chance of replication (Keppel, 1991). Statistical power was judged to be satisfactory in the present study. Power was calculated to be 0.80 for an effect size of 0.50, $t(25) = 1.71$, $p < .05$, GPower Version 3.1.

Reliability

Inter-rater estimates of reliability were calculated for ratings of sentence intelligibility, listener effort, and reduced loudness in no added background noise and 65 dB SPL multi-talker background noise. The values obtained for inter-rater reliability ranged from 0.87 to 0.97, $p < .01$, in the no added background noise condition and from 0.88 to 0.99, $p < .001$, in the 65 dB multi-talker background noise condition. These Intraclass Correlation Coefficient values demonstrate overall good reliability between listeners for the ratings of sentence intelligibility, listener effort, and reduced loudness. Scores from each listener for each listening task were measured against each other to obtain intra-rater reliability values. Each of the 10 listener participants re-measured 18.18% of the data to determine intra-rater reliability. **Table 2** reports Cronbach's alpha which revealed an overall intra-rater reliability estimate of 0.89, $p < .01$ across tasks, which indicates good intra-rater reliability across all task measurements.

Objective 1

The first objective sought to evaluate and compare listener ratings of perceived speech loudness with acoustic speech intensity data in both the no added background noise condition and the 65 dB SPL of multi-talker background noise condition. **Table 3** shows the mean and standard deviation values for the acoustic speech intensity data obtained from the speakers with PD across the two noise conditions. Our results show that our speakers with PD increased their speech intensity by approximately 6 dB SPL in 65 dB SPL of background noise as compared to the no noise condition.

Table 2

Summary of Intra-Rater and Inter-Rater Estimates of Reliability Across all Task Measurements

	Intra-rater reliability	Inter-rater reliability	*p* value
Average Intraclass Correlation Coefficient	.90	.96	<.01
Cronbach's alpha	.89	.96	

Pearson's correlation between visual analogue scale ratings of perceived speech loudness and acoustic speech intensity data was significant in both the no added background noise condition, $r(22) = -.54$, $p = .01$, and in the 65 dB SPL multi-talker background noise condition, $r(22) = -.86$, $p < .001$. Overall, these results suggest that acoustic measures of speech intensity are significantly related to perceived loudness rated by our listeners, especially in 65 dB of multi-talker background noise.

Objective 2

The second objective sought to evaluate and compare transcription-based sentence intelligibility scores, ratings of listener effort, and ratings of perceived speech loudness in the two background noise conditions. Three paired samples *t* tests were conducted to evaluate these variables across the two noise conditions.

The comparison of sentence intelligibility scores revealed significant differences between the no added background noise condition ($M = 85.54$, $SD = 14.44$) and the 65 dB SPL multi-talker background noise condition ($M = 46.17$, $SD = 32.37$), $t(21) = 7.19$, $p < .001$, as illustrated in **Figure 2**. The comparison of ratings of listener effort revealed significant differences between effort ratings in the no added background noise condition ($M = 35.43$, $SD = 22.46$) and the 65 dB SPL multi-talker background noise condition ($M = 68.62$, $SD = 25.77$), $t(21) = -8.0$, $p < .001$ (see **Figure 2**). The comparison of perceived speech loudness ratings revealed significant differences between listener ratings in the no added background noise condition ($M = 32.70$, $SD = 24.38$) and the 65 dB SPL multi-talker background noise condition ($M = 54.80$, $SD = 29.90$), $t(21) = -4.19$, $p < .001$ (see **Figure 2**).

Overall, the results of Objective 2 suggest that the introduction of a moderate intensity level of multi-talker background noise significantly reduced sentence intelligibility scores. In addition, the introduction of 65 dB SPL multi-talker background noise also increased ratings of listener effort, suggesting that background noise may not only impair a listener's understanding of what is being said by an individual with PD and hypophonia, but also that it creates a more effortful listening environment. These results also suggest that reduced loudness was perceived as more impaired in the 65 dB SPL multi-talker background noise.

Objective 3

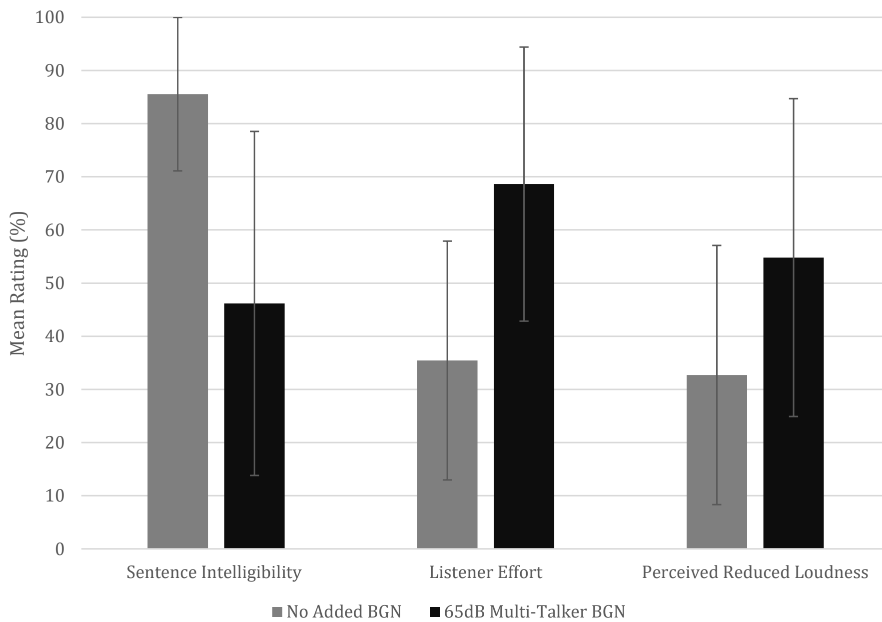
The third objective evaluated the relationship between sentence intelligibility scores and ratings of listener effort in the two background noise conditions. Pearson's correlation between sentence intelligibility scores ($M = 85.54$, $SD = 14.44$) and ratings of listener effort ($M = 35.43$, $SD = 22.46$) in the no added background noise condition was significant, $r(21) = -.89$, $p < .001$, as illustrated in **Figure 3**. The coefficient of determination suggests that 79.57% of the variance in listener effort is explained by sentence intelligibility scores when no added background noise is present. Pearson's correlation between sentence intelligibility scores ($M = 46.16$, $SD = 32.36$) and ratings of listener effort ($M = 68.62$, $SD = 25.77$) in the 65 dB SPL multi-talker background noise condition was significant, $r(21) = -.96$, $p < .001$, as illustrated in **Figure 4**. The coefficient of determination suggests that 92.74% of the variance in listener effort is explained by sentence intelligibility scores with the addition of 65 dB multi-talker background noise. In general, these negative correlations show that as intelligibility ratings increase, ratings of listener effort decrease, and as intelligibility ratings decrease, ratings of listener effort increase in both noise conditions.

Table 3

Overall Mean Speech Intensity Levels (dB SPL) in Each Noise Condition

	0 dB SPL	65 dB SPL
Mean	66.9	73.5
SD	4.6	2.1

Figure 2



Mean scores for overall ratings of sentence intelligibility, listener effort, and perceived loudness in both noise conditions. Error bars represent standard deviations. BGN = background noise.

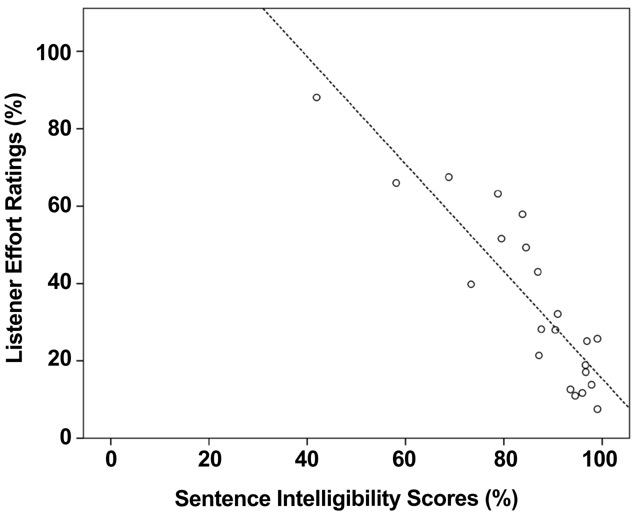
Objective 4

Objective 4 examined the strength of the relationship between ratings of listener effort and perceived speech loudness in the two background noise conditions. **Figure 5** shows the Pearson's correlation between ratings of listener effort ($M = 35.43$, $SD = 22.46$) and reduced loudness ratings ($M = 32.70$, $SD = 24.38$) in the no added background noise condition was significant, $r(21) = .84$, $p < .001$. The coefficient of determination suggests that 71.06% of the variance in listener effort is explained by ratings of reduced loudness when no added background noise is present. Pearson's correlation between ratings of listener effort ($M = 68.62$, $SD = 25.77$) and reduced loudness ratings ($M = 54.8$, $SD = 29.89$) in the 65 dB multi-talker background noise condition shown in **Figure 6** was significant, $r(21) = .96$, $p < .001$. The coefficient of determination suggests that 92.54% of the variance in listener effort is explained by ratings of reduced loudness with the addition of 65 dB multi-talker background noise. These positive correlations show that as ratings of listener effort increase, reduced loudness ratings also increase (i.e., the speaker with PD is rated as less intense/more quiet), and as ratings of effort decrease, reduced loudness ratings also decrease (i.e., the speaker with PD is rated as more intense/louder).

Objective 5

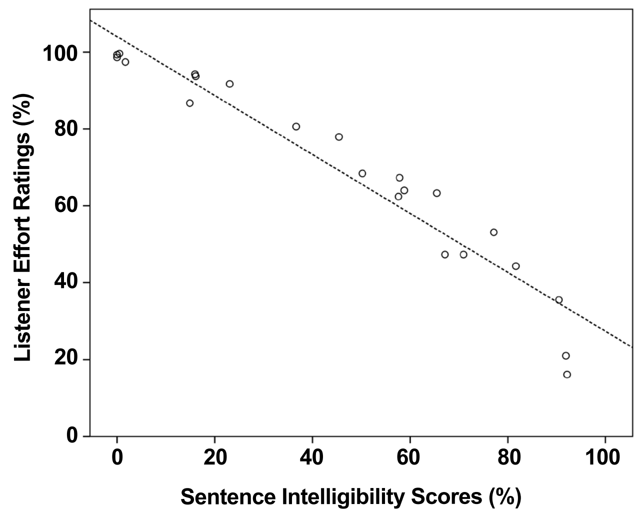
The fifth objective examined the correlations between ratings of sentence intelligibility and perceived speech loudness in the two background noise conditions. **Figure 7** shows Pearson's correlation between sentence intelligibility scores ($M = 85.54$, $SD = 14.44$) and reduced loudness ratings ($M = 32.70$, $SD = 24.38$) in the no added background noise condition was significant, $r(21) = -.68$, $p < .001$. The coefficient of determination suggests that 46.79% of the variance in sentence intelligibility scores is explained by ratings of reduced loudness when no added background noise is present. Pearson's correlation between sentence intelligibility scores ($M = 46.16$, $SD = 32.36$) and reduced loudness ratings ($M = 54.8$, $SD = 29.89$) in the 65 dB multi-talker background noise condition shown in **Figure 8** was significant, $r(21) = -.97$, $p < .001$. The coefficient of determination suggests that 93.32% of the variance in sentence intelligibility scores is explained by ratings of reduced loudness with the addition of 65 dB multi-talker background noise. These correlations show that as sentence intelligibility scores increase, reduced loudness ratings decrease (i.e., the speaker with PD is perceived as louder), and as sentence intelligibility scores decrease, reduced loudness ratings increase (i.e., the speaker with PD is perceived as less intense).

Figure 3



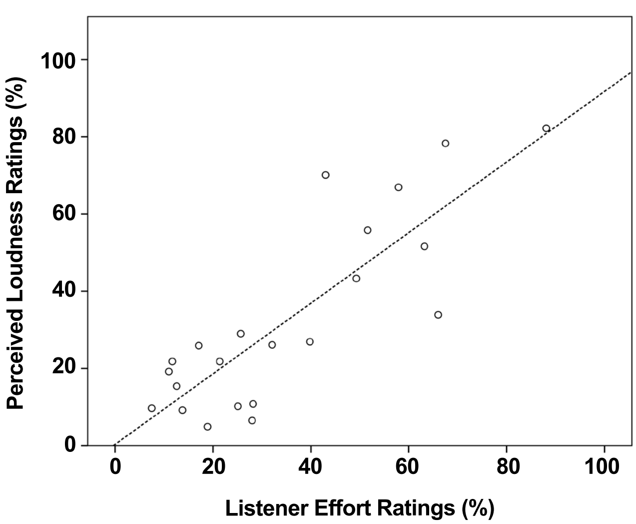
Sentence intelligibility scores vs. ratings of listener effort (no added background noise).

Figure 4



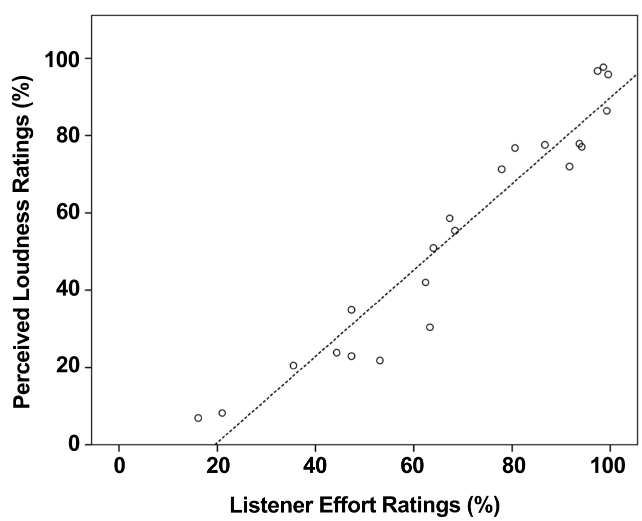
Sentence intelligibility scores vs. ratings of listener effort (65 dB multi-talker background noise).

Figure 5



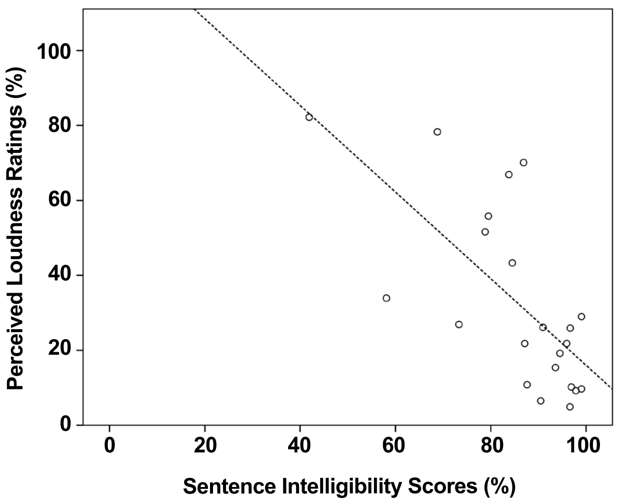
Ratings of listener effort vs. reduced loudness ratings (no added background noise). Loudness Score Scale: 0 = normal loudness/speech intensity, 100 = severely impaired loudness/speech intensity.

Figure 6



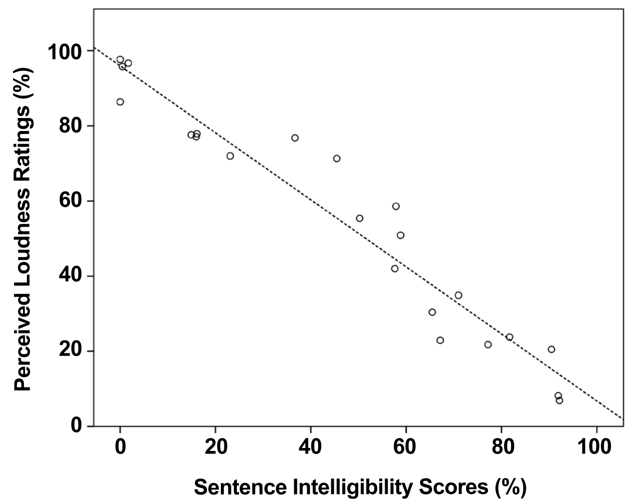
Ratings of listener effort vs. reduced loudness ratings (65 dB multi-talker background noise). Loudness Score Scale: 0 = normal loudness/speech intensity, 100 = severely impaired loudness/speech intensity.

Figure 7



Sentence intelligibility scores vs. reduced loudness ratings (no added background noise). Loudness Score Scale: 0 = normal loudness/speech intensity, 100 = severely impaired loudness/speech intensity.

Figure 8



Sentence intelligibility scores vs. reduced loudness ratings (65 dB multi-talker background noise). Loudness Score Scale: 0 = normal loudness/speech intensity, 100 = severely impaired loudness/speech intensity.

Discussion

In this study, listeners rated the speech of individuals with PD and hypophonia in two noise conditions. Across the two noise conditions, listeners rated sentence intelligibility, perceived speech loudness, and the amount of effort required to transcribe the speech of individuals with PD and hypophonia as their primary dysarthric symptom. Longer SIT sentences of 13–15 words in length were selected to rate sentence intelligibility because longer sentences are considered more complex to produce (Altmann & Troche, 2011). These longer, more complex sentences may have been more taxing on the speech production mechanism of speakers with PD, making it more challenging for these individuals with hypokinetic dysarthria to produce intelligible sentences in either of the noise conditions. More complex sentences can also make it more difficult for listeners to predict and fill in content when the speech signal is already distorted, and therefore may be representative of everyday speech demands (Yorkston & Beukelman, 1981; Yorkston, Strand, & Kennedy, 1996). Results demonstrated differences in sentence intelligibility scores, ratings of perceived speech loudness, and ratings of effort between background noise conditions. Results also demonstrated that these variables were significantly correlated regardless of noise condition.

When comparing sentence intelligibility scores across noise conditions, comparisons revealed significantly higher sentence intelligibility scores in the no added background noise condition as compared to the 65 dB multi-talker background noise. The sentence intelligibility results are consistent with the findings of Adams et al. (2008) and Dykstra et al. (2012a) who also found that the introduction of background noise significantly reduced sentence intelligibility scores. Our analysis shows the dramatic and significant effect that moderate intensity levels of multi-talker background noise have on a listener's ability to understand what was being spoken by speakers with PD. Although most of the speakers with PD in the current study were judged to have mild-moderately impaired speech intelligibility in no added background noise, the introduction of moderate intensity multi-talker background noise significantly degraded the speech intelligibility of our sample of speakers with PD and hypophonia.

Despite relatively high sentence intelligibility scores in no added background noise, listeners still reported using effort when listening to and transcribing hypophonic speech. This is supported by Beukelman et al. (2011) who indicated that measuring sentence intelligibility alone does not provide information on the perceptual load experienced by a listener when transcribing a disordered speech signal. Beukelman et al. measured attention allocation and found that dysarthric speech with relatively high sentence intelligibility still resulted in an increased perceptual load for listeners. Our findings suggest that even in ideal, quiet listening conditions listeners use effort when listening to and trying to understand individuals with hypophonia and PD. Furthermore, previous research has indicated that listeners have more difficulty understanding disordered speech in comparison to normal speech (Dykstra, 2007). Like the current findings and using the same visual analogue scale anchors for assigning ratings of listener effort to individuals with PD and control participants, Dykstra (2007) found that in no added background noise listeners assigned higher effort ratings for participants with PD than control participants in a conversational intelligibility task. When noise was introduced, this pattern was exacerbated across a variety of multi-talker background noise conditions.

There is empirical literature suggesting that listeners need to exert an increased amount of effort when listening to dysarthric speech in order to understand what is being said (e.g., Dykstra, 2007; Landa et al., 2014; Whitehill & Wong, 2006). This is consistent with the previous findings of Whitehill and Wong (2006) who observed a strong negative correlation between speech intelligibility scores and listener effort in various dysarthria types. As well, Landa et al. (2014) demonstrated that when listeners rated "ease of listening" for dysarthric speech, poorer intelligibility scores were associated with increased listening effort. The current study demonstrates that this is even more relevant with the addition of background noise. When background noise was introduced, sentence intelligibility scores decreased to *severely impaired* according to the SIT levels of impairment, and ratings of listener effort increased. The addition of background noise, in comparison to the no added background noise condition, made it even more difficult for listeners to understand the speech signal of speakers with hypophonia. It is possible that our listeners used information processing strategies relying on context and sentence structure in addition to the speech signal to determine what was being spoken (Beukelman et al., 2011). This additional effort and reallocation of resources by the listeners could contribute to cognitive overload and may cause a barrier to communicative participation and reduce opportunities for individuals with PD to communicate (Beukelman et al., 2011; Dykstra et al., 2007). This is worthy of future study.

The comparison of reduced loudness ratings across noise conditions revealed that listeners perceived speakers with PD to be significantly louder in the no added background noise condition compared to the 65 dB multi-talker background noise condition. These results demonstrate that a listener's perception and ratings of the severity of hypophonia are exacerbated in noise, especially considering the acoustic speech intensity data that demonstrates speakers with PD had increased their speech intensity (i.e., were louder) in the 65 dB SPL multi-talker background noise condition, suggesting a Lombard effect was present.

Previous studies have demonstrated the Lombard effect where in background noise control participants regulated their speech intensity, duration, and frequency to be heard over the noise (Adams et al., 2005, 2006; Lane & Tranel, 1971; Patel & Schell, 2008). Adams et al. (2005, 2006, 2008) have previously demonstrated the relationship between background noise and speech intensity regulation in individuals with PD and hypophonia. Adams et al. (2005) found that individuals with PD exhibited a Lombard effect, with participants with PD demonstrating consistently lower levels of speech intensity in comparison to control participants. In a study by McAuliffe, Kerr, Gibson, Anderson, and LaShell (2014), five individuals with PD read sentences from the SIT using their normal speech loudness as well as at a level they felt was two times louder than their normal speech loudness. This resulted in sentence intelligibility scores increasing from an average of 45.23% to 60.45% and suggested that speech intensity has a direct impact on intelligibility (McAuliffe et al., 2014). The speech intensity of individuals with PD has also been found to be more variable than that of control participants (Dysktra et al., 2012b).

However, it is also important to consider speech-to-noise ratios. Speech-to-noise ratios compare the intensity level of speech to the intensity level of background noise. Although our listeners perceived the speech of individuals with PD to be reduced in loudness in the noise condition, they were actually more intense (louder) in order to be heard over the noise. Our findings are similar to that of Leszcz (2012) who demonstrated that across tasks people with PD spoke at a higher intensity in the 65 dB condition than in no noise. Therefore, our listener ratings of reduced loudness were affected by the level of background noise (in this case 65 dB), as well as the speech-to-noise ratio. Studies that have considered speech-to-noise ratios indicate that individuals with PD have lower speech-to-noise ratios than control participants in background noise (Adams et al., 2008). As well, with an increase in background noise comes a decrease in speech-to-noise ratios, which was found to have a negative impact on intelligibility (Adams et al., 2008). This suggests that a similar phenomenon is occurring in the current study, as the presence of background noise also resulted in ratings of both reduced intelligibility and reduced loudness. It appears as if our speakers with PD did demonstrate a Lombard effect when noise was presented, but the observed increase in speech intensity was not sufficient to be heard adequately over the noise (i.e., reduced speech-to-noise ratio).

Although we found significant correlations regardless of noise condition, it remains important to assess speech intelligibility in both optimal and sub-optimal communicative environments. In clinical settings, speakers with PD may seem appropriately loud due to the lack of background noise or they may increase their speech intensity because they have learned to do so in treatment, and this may or may not be generalized to environments outside the treatment room (Dykstra, 2007; Dykstra et al., 2012a). Tjaden and Wilding (2011) suggested that intelligibility scores derived from validated intelligibility tests, such as the SIT, when administered in a quiet environment are not indicative of actual intelligibility in an ecologically valid context or in spontaneous speech. Adams et al. (2008) demonstrated that individuals with hypophonia had overall significantly lower conversational intelligibility scores in noise when compared to control participants, despite relatively unimpaired speech intelligibility when tested in quiet conditions. The results of the current study reflect this result since the SIT intelligibility ratings were within the mildly impaired range in the no added background noise condition and in 65 dB of multi-talker background noise sentence intelligibility decreased to reflect a severe impairment. This finding was also demonstrated by Dykstra et al. (2012a) when studying the conversational intelligibility of individuals with hypophonia in noise. Their study found that without added background noise there was no significant difference in the intelligibility scores of individuals with PD versus control participants. However, the speech intensity of the PD group was lower and had more variability than the control participants and when background noise was introduced participants with PD had lower conversational intelligibility scores (Dykstra et al., 2012a). The results of previous studies, as well as the current study, all demonstrate the importance of assessing the speech intelligibility of speakers with hypophonia and PD in a variety of contexts including noise, even if these speakers are quite intelligible in quiet environments. This assessment would provide clinicians more information concerning the intelligibility of their clients across different noise conditions so management plans can be tailored, and meaningful goals can be set regarding loudness and intelligibility profiles. This information also may serve to provide strategies for the communicative partner (i.e., the listener) in order to reduce listener effort and, therefore, maximize communicative interactions within the speaker–listener dyad. These strategies may include instruction relating to being face-to-face when communicating, having important conversations in quiet environments, and amplifying the speaker's voice when speaking in noisy environments.

Limitations

This study did not include speech samples of individuals without PD to serve as a control group of speakers. It would have strengthened the study to include control speakers to determine and directly compare how the listeners rate intelligibility, perceive effort, and perceive loudness in healthy speakers without PD and hypophonia. The addition of a control group of speakers is worthy of future study.

Our eligibility criteria limited our listener pool to a young, unfamiliar, and naïve population that is not representative of all listeners. In some cases, younger listeners have been found to provide higher intelligibility scores than older listeners (Jones, Mathy, Azuma, & Liss, 2004). This could be due to a natural cognitive decline that occurs with age, or in some cases—in particular older men—hearing loss (Pennington & Miller, 2007). Various studies (i.e., Liss, Spitzer, Caviness, & Adler, 2002; Tjaden & Liss, 1995a, 1995b) have demonstrated that familiar non-naïve listeners are better able to recognize speech than unfamiliar naïve listeners, and therefore give higher intelligibility scores. However, Pennington and Miller (2007) suggested that with standardized listening conditions, factors such as age, gender, and familiarity may not have a significant impact on intelligibility results.

This study used more complex sentences derived from the SIT; however, these sentences do not represent the ecological validity and complexity of natural conversational speech. Some literature suggests that hypophonia is most evident in conversational speech tasks (Fox & Ramig, 1997; Ho et al., 1999, 2000). However, Dykstra (2007) suggested that sentence intelligibility and conversational intelligibility are comparable in validity. Longer sentences from the SIT were selected to make the stimuli more ecologically valid than shorter sentences.

Since hypophonia was the primary dysarthric speech feature for the speakers in this study, it should be considered that the recordings of individuals with PD likely represents a subgroup of individuals with PD that is not representative of all speakers with hypokinetic dysarthria. Therefore, the results of this study may not be generalizable to the general PD population that may be experiencing different elements of hypokinetic dysarthria such as prosodic abnormalities or impairments in speech rate. Future studies may wish to examine and consider a more heterogeneous group of speakers with PD to ascertain the variety of speech symptoms that impact both speech intelligibility and ratings of listener effort.

Conclusion and Future Directions

Our results contribute to the evidence base demonstrating that background noise can impact listener ratings of sentence intelligibility, listener effort, and perceived speech loudness. The results of this study demonstrate that when assessing hypophonia in PD (and presumably other dysarthria types), gathering speech intelligibility data in quiet environments has the potential to underestimate the negative impact that background noise has on speech intelligibility and listener effort in this clinical population. To improve the communicative abilities of people with PD, clinicians need to consider that intelligibility and loudness have an impact on listener effort. Clinicians should ensure that they educate clients and families about good communicative practices such as reducing background noise and being face-to-face during a conversation. These educational strategies could help to reduce listener effort and provide more successful communication for people with PD.

We also need to further our knowledge and understanding of listener effort and the impact it has on communicative participation. Future exploration of the relationships among listener effort, speech intelligibility, speech intensity, and other speech symptoms associated with hypokinetic dysarthria (i.e., articulation, rate, voice quality, and prosodic abnormalities) is required. This is especially relevant because each speech subsystem (i.e., articulatory, respiratory, laryngeal, and velopharyngeal) likely contributes to speech intelligibility and listener effort in a cumulative, but differential way (Dykstra et al., 2007). It has been suggested that this information could help to provide clinicians with a better idea of what speech symptoms have a greater impact on speech intelligibility, as well as information on the underlying physiological mechanisms of hypokinetic dysarthria in PD (Yahalom, Simon, Thorne, Peretz, & Giladi, 2004). More research is required to understand the interaction of speech intelligibility, perceived speech loudness, and listener effort.

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Disclosures

No conflicts of interest, financial or otherwise, are declared by the authors.