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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Health and Rehabilitation Sciences

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THE EFFECT OF MULTITALKER BACKGROUND NOISE ON SPEECH INTELLIGIBILITY IN PARKINSON'S DISEASE AND CONTROLS

(Spine title: The Effect of Background Noise on Speech Intelligibility)

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by

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Graduate Program in Health & Rehabilitation Sciences

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

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THE UNIVERSITY OF WESTERN ONTARIO
School of Graduate and Postdoctoral Studies

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Talia Michelle Leszcz

entitled:

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Abstract

This study investigated the effect of multi-talker background noise on speech intelligibility in participants with hypophonia due to Parkinson's disease (PD). Ten individuals with PD and 10 geriatric controls were tested on four speech intelligibility tasks at the single word, sentence, and conversation level in various conditions of background noise. Listeners assessed speech intelligibility using word identification or orthographic transcription procedures. Results revealed non-significant differences between groups when intelligibility was assessed in no background noise. PD speech intelligibility decreased significantly relative to controls in the presence of background noise. A phonetic error analysis revealed a distinct error profile for PD speech in background noise. The four most frequent phonetic errors were glottal-null, consonant-null in final position, stop place of articulation, and initial position cluster-singleton. The results demonstrate that individuals with PD have significant and distinctive deficits in speech intelligibility and phonetic errors in the presence of background noise.

Keywords

Speech intelligibility, hypophonia, phonetic errors, Parkinson's disease, background noise.

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Chapter 1

1 Introduction

1.1 Parkinson's Disease

Parkinson's disease (PD) is a progressive neurodegenerative disorder associated with various motor control and speech impairments. The disorder is named after James Parkinson whose essay *The Shaking Palsy*, first published in 1817, highlights the key features of the illness (Parkinson, 2002). PD onset usually occurs later in life with a mean onset age of 55 and much higher incidence by 70 years of age (Dauer & Przedborksi, 2003). Reported incidence rates are between 8-18 per 100 000 persons (de Lau & Breteler, 2006). Currently there are over 5 million diagnosed cases of PD in the world, a number that is predicted to increase to around 9 million by 2030 due to the world's ageing population (Dorsey et al., 2006). The term Parkinsonism refers to the clinical symptoms of the disease regardless of the etiology, whereas PD traditionally refers only to the idiopathic form of the disease (Duffy, 2005). The disease is characterized by the degeneration of dopaminergic neurons in the substania nigra. PD is commonly known as a disease of motor control and about 75% of all individuals with PD suffer from a speech or voice disorder (Ramig, Countryman, O'Brien, Hoehn, & Thompson, 1996). Dopamine reduction is present in all individuals with PD and it is responsible for the diminished motor and speech control observed in this population (Spencer, Morgan, & Blond, 2009).

The cardinal features of PD motor impairment involve akinesia, rigidity, tremor and postural instability (Duffy, 2005; Gelb, Oliver & Gilman, 1999). When present, tremor typically occurs when the individual's limb is at rest. Although rest tremor predominates, individuals with PD can also develop tremor during actions and postures throughout the course of the disease (Gelb et al., 1999). Akinesia can include bradykinesia (slowness of movement), hypokinesia (reduced movement amplitude) and a reduction in spontaneous or associative movements. Akinesia also can manifest as a lack of facial animation and a rigid, unsmiling and expressionless face (Dauer & Przedborski, 2003; Duffy, 2005). Postural instability usually occurs later in the disease, and can be associated with an increase in falling and difficulty supporting oneself as well as a shuffled gait (Gelb et al., 1999). Individuals with PD also experience difficulty writing due to their increased rigidity, inability to control motor coordination and reduced movement amplitude. Writing is often illegible and very small, a symptom known as micrographia (Gelb et al., 1999).

1.2 Hypokinetic Dysarthria

Hypokinetic dysarthria is the motor speech disorder that Darley, Aronson and Brown (1969) used to describe the speech impairments associated with idiopathic PD. It is a disease of the basal ganglia control circuit, which plays an important role in movement control. Damage to this area can affect all levels of the speech system (Duffy, 2005). Although the term hypokinetic dysarthria was originally developed to describe the speech of idiopathic PD it is frequently used to describe the Parkinson-like speech of other similar degenerative disorders such as progressive supranuclear palsy (PSP), multi-system atrophy (MSA), and parkinsonism due to vascular or infectious causes (Duffy, 2005).

Hypokinetic dysarthria refers to the reduction in the range, speed and force of speech movements, which are hypothesized to be the primary cause of the speech deficits in PD. The characteristics of hypokinetic dysarthria include reduced loudness (i.e., hypophonia), monopitch, monoloudness, disordered rate of speech, prosodic abnormalities, impaired articulation and abnormal voice quality (Darley, et al., 1969). These speech deficits result in the generation of a distorted acoustic signal and as a result, reduced intelligibility.

As the disease progresses, speech degrades, however at a variable rate from motor impairments. Speech intelligibility becomes increasingly reduced making communication difficult, which can limit social interactions, interfere with employment and consequently may have a detrimental effect on the individual's quality of life (Brod, Mendelsohn & Roberts, 1998).

Hypokinetic dysarthria is most frequently manifested in prosodic, articulation and voice impairments (Duffy, 2005). Prosodic impairments such as monopitch and monoloudness, typical of individuals with PD are measured acoustically as a reduction in fundamental frequency (pitch) and loudness variability (Ramig, Fox & Sapir, 2004). Variable speech rate is a common problem manifesting either in rate reduction or more commonly in rapid speech (Ramig et al., 2004). Articulation problems present in about half of all PD patients and become increasingly prevalent as the disease progresses (Logemann, Fisher, Boshes, & Blonsky, 1978). Phoneme misarticulations and imprecise consonant production are associated with a reduction in the amplitude and force of movement of the tongue, lips and jaw. In addition, the coordinated timing between laryngeal and oral movements can be impaired. Logemann et al. (1978) also suggest that inadequate narrowing of the vocal tract may contribute to the distortion of certain speech sounds. Potential acoustic correlates of imprecise consonant articulation in PD speech include spirantization, and the timing of vocal onset and offset (Adams & Dykstra, 2008). Spirantization refers to the presence of fricative like noise during stop consonants and is a characteristic unique to Parkinsonian dysarthria. Individuals with PD show higher rates of spirantization than healthy geriatrics, particularly of stop consonants that are not normally spirantized. Individuals with PD often demonstrate longer voice onset times and voicing through closure during voiceless stops due to their reduced force of movement and inability to make adequate vocal fold closure to produce clearly articulated stops (Weismer, 1984). Voice disorders are the most frequently occurring PD speech impairment. Voice disorders, such as, hoarseness, roughness, tremulousness, breathiness and harshness occur in almost 90% of individuals with PD (Logemann et al., 1978). Disordered voice quality is measured acoustically using phonatory instability measures such as jitter, shimmer and harmonics-to-noise ratio. (Ramig et al., 2001; Ramig et al., 2004). Laryngeal disorders have also been observed. Less commonly, resonance problems such as hypernasality or fluency disorders (i.e., stuttering) can occur in some individuals. Dysfluencies typically include syllable repetitions, prolonged or shortened syllables and abnormally long pauses (Logemann et al., 1978).

1.3 Hypophonia

Hypophonia is a common problem in individuals with PD that has the potential to impact speech intelligibility and inevitably, effective communication. Hypophonia refers to reduced speech intensity and has been well documented anecdotally as well as demonstrated in a number of perceptual studies (Ackermann & Ziegler, 1991; Adams, 1997; Ho, Iansek & Bradshaw, 1999; Ramig et al., 2004). Individuals with PD often complain of being frustrated from frequent requests to speak louder and to repeat themselves despite thinking that they are speaking at a normal volume (Adams, 1997; Ho, Bradshaw & Iansek, 2000).

Hypophonia is recognized as a distinctive feature of Parkinsonian dysarthria, however the acoustic correlates of these perceptual features have been difficult to find. Individuals with hypophonia have been shown to demonstrate speech intensity levels that are significantly lower (2-3 decibels (dB)) than healthy adults (Adams et al., 2006b; Adams, Haralabous, Dykstra, Abrams & Jog, 2005; Fox & Ramig, 1997). A 2-4 dB decrease in speech intensity is perceived as a 40% reduction in speech volume (Fox & Ramig, 1997). Individuals with PD also demonstrate significantly lower maximum speech intensity (6-7 dB) than healthy adult controls (Adams et al. 2006b). In addition, Ho, Iansek & Bradshaw (2001) demonstrated a progressive decrease in speech intensity throughout the span of individual utterances similar to the decrease in amplitude of sub-movements within a motor sequence. The authors suggest that hypophonia is the speech analogue of hypokinesia, however this hypothesis has yet to be systematically tested (Ho, Iansek, & Bradshaw, 2001; Ho, Bradshaw, & Iansek, 2008).

The lack of accord between perceptual and acoustic measures suggests that there may be additional parameters contributing to the perception of reduced speech intensity in individuals with PD (Adams, 1997). One factor contributing to the lack of acoustic measures of reduced speech intensity may be due to the difficulty obtaining natural speech samples in laboratory settings and the lack of standardization in intensity measures, speech tasks and testing environment. The discordant findings between studies indicate the importance of investigating speech intensity in more ecologically valid contexts. As well, it is possible that other factors such as phonatory or respiratory impairment, poor voice quality and a higher signal to noise ratio may contribute to the perception of reduced loudness in PD.

1.4 Intelligibility

The concept of speech intelligibility is of primary importance in dysarthria because reduced intelligibility is a frequent and almost universal consequence of dysarthric speech (Yorkston & Beukelman, 1984). Intelligibility has also been investigated extensively in the areas of military systems, electronic and hearing-impaired speech recognition (Kryter, 1994). Intelligibility assessment of hypokinetic dysarthria and hypophonia associated with PD is a central issue in speech therapy with the ultimate goal of intervention to increase intelligibility (Connolly, 1986; Yorkston & Beukelman, 1980). Intelligibility may serve as an index of disease severity and allow for examination of the extent and nature of speech impairments.

Intelligibility is broadly viewed as successful oral communication and the ability of the listener to comprehend the speakers' message. Specifically, intelligibility has been defined by Kent, Weismer, Kent & Rosenback (1989) "as the degree to which the speaker's intended message is recovered by the listener" (p. 483). Similarly, Hustad and Beukelman (2002) define intelligibility as the listeners' ability to parse out lexical and phonetic features from the acoustic signal of the speakers' message. Intelligibility is dependent on both the speakers' ability to produce a message and the listeners' ability to perceive the intended message (Walshe, Miller, Leahy & Murray, 2009). Intelligibility is a relative and intrinsically context dependent construct that is a function of a number of communication variables and interactive processes including the speakers' articulation, phonation, resonance and prosody as well as visual cues, listener familiarity and speech topic (De Bodt, Hernandez-Diaz, & Van de Heyning, 2002). These authors suggest that intelligibility can be viewed as a linear combination of each of these factors. It is imperative to control all variables when assessing intelligibility in order to identify the breakdown in communication contributing to the reduced intelligibility.

1.5 Intelligibility Measurement

Intelligibility is a perceptual measure that is based on the accuracy with which listeners are able to understand a spoken utterance. It varies along a prothetic continuum because it is a stimulus that is additive in nature and is assessed as a quantity rather than as a quality dimension (Kent et al., 1989). An intelligibility score can provide useful clinical information such as a quantification of the severity of a speech disorder. It can also be used to evaluate the effects of treatment, document disease progression, and in some specialized testing procedures (i.e., phonetic or phonemic intelligibility tests) it can provide insight into speech subsystem impairments including respiration, phonation, articulation and resonation (Hustad, 2007).

Traditionally, intelligibility has been measured by three basic methods; orthographic transcription procedures, multiple choice correct word identification and perceptual rating scales. Orthographic transcription and multiple choice correct word identification are examples of objective measures and have greater ecological validity but can be more difficult to obtain than subjective measures (Yorkston & Beukelman, 1981). Typically, speech samples can include single word, sentence and narrative samples that can be spoken spontaneously, read or imitated by the speaker. Reading and imitation are examples of structured speech tasks and therefore maintain greater reliability due to the consistency with which they can be employed. However, structured speech tasks lack in face validity compared to extemporaneous speech tasks (Tjaden & Wilding, 2010). Subjective measures such as listener quantification of intelligibility of the speakers' message through perceptual rating scales are more easily obtained than objective measures but have limited reliability (Hustad, 2007). Perceptual rating scale procedures involve having a listener estimate the level of intelligibility using a specific severity scale. Rating scale techniques include percent estimation of intelligible words and interval scaling. Various scales are available to estimate intelligibility (i.e. equal appearing interval scales, percent estimation scales, visual analog scales, etc.). Interval scaling, usually employ 5, 7 or 9-point scales with or without interval descriptions. However its use in intelligibility measures is debatable because it is difficult for listeners to partition intelligibility into equal intervals along a continuum due to the quantitative nature of intelligibility (Schiavetti, 1992). Percent estimation such as direct magnitude estimation (DME) requires a listener to make a numerical estimate of intelligibility and is more applicable to prothetic continua. DME is a perceptual ratio technique that does not constrain listeners to judge within fixed maximum or minimum values (Schiavetti, 1992). DME can employ either modulus free or modulus-scaling techniques. Modulus free techniques require listeners to assign a value of 100 to the initial speech sample and rate all subsequent samples in reference to the first sample. Modulus scaling techniques include a standard modulus against which all estimates are compared. DME with a mid-range example as a modulus yields more interpretable estimations and is easier for listeners to use because they are provided with a comparable standard (Weismer & Laures, 2002). Perceptual rating scales yield useful intelligibility estimates but reveal nothing about the nature of the intelligibility deficit or the misidentified speech units.

Each method of measurement can reveal different elements that contribute to intelligibility deficits in dysarthric speakers. Measurement of intelligibility is challenging and can be somewhat unreliable due to interactions between the myriad of factors involved in communication. It is critical when measuring intelligibility that all variables are tightly controlled such as stimuli, listener context, testing environment and variability between objective and subjective measures and stimulus presentation. Accurate measurement of intelligibility is critical because of its implications for clinical decision-making.

1.6 Intelligibility in Noise

To maintain adequate intelligibility in the presence of background noise it is necessary for speakers to increase the level of their speech relative to that of the noise. Signal-to-noise ratio refers to the effect of background noise on speech transmission and has far reaching implications in the area of speech intelligibility. It has been studied extensively in areas such as hearing impairments, soldiers in combat, aircraft pilot communications, speech transmission systems and speech recognition technology (Kryter, 1994). Increasing levels of background noise exerts a distorting or masking effect on the frequencies and acoustic qualities of speech (Kryter, 1994; Miller & Niceley, 1955). Acoustically, loud speech is characterized by an increase in fundamental frequency (F0) and sound pressure level (SPL). Loud speech requires an increase in buildup of subglottal pressure and is associated with spectral and temporal changes (Huber, Chandrasekaran & Wolstencroft, 2005; Turner, Martin & de Jonge, 2008). Loud speech, as well as amplified speech in PD has been associated with increases in intelligibility due to the increase in signal-to-noise ratio (Neel, 2009). Individuals with

PD often have respiratory and/or phonatory impairments consequently resulting in problems of reduced speech intensity and hypophonia and difficulty maintaining intelligible speech in the presence of background noise. Adams and colleagues (2008) demonstrated that individuals with PD will modulate their speech intensity in the presence of background noise, but continually show reduced signal-to-noise ratios relative to controls. Individuals with PD consistently demonstrated signal-to-noise ratios that were 2-3 dB lower than controls and were associated with 20-30% reductions in conversational speech intelligibility (Adams et al., 2008).

Previous research on the effect of background noise and speech intelligibility has focused on the nature of the perceptual errors in speech recognition in the context of background noise (Miller & Niceley, 1955; Dubno & Levitt, 1981; Phatak, Lovitt & Allen, 2008). It has been well documented that listener familiarity and the probability of occurrence of a given speech-sound, word or phrase increases the likelihood of correct perception even in the presence of background noise (Miller, Heise & Lighten, 1951; Kalikow, Stevens & Elliot, 1977; Zhao & Jurafsky, 2009). Speech features, such as articulatory or acoustic features form the basis of perceptual recognition of speech. Some features include; manner, place of maximum constriction, and voicing (Dubno & Levitt, 1981). If one or more of these features is masked by background noise the sound may become confused with other sounds that share some of the same speech features. While the relative contribution of a given acoustic feature in the identification of a speech sound can vary depending upon context and noise levels, it is assumed that as the number of shared features between two sounds increases, the discriminability between them decreases (Dubno & Levitt, 1981; Miller & Nicely, 1955).

The systematic investigation of masking noise on speech perception allows for the development of confusion matrices to quantify the perceptual elements of speech sounds based on similar sounds with which they are commonly confused (Phatak, Lovitt & Allen, 2008) The development of confusion matrices for English sounds in different noise contexts aids in the understanding of speech recognition systems and has far reaching implications in the development of hearing aids and automatic speech recognition devices and provides insight into human speech recognition. Unfortunately, the perception of speech in noise and the development of confusion matrices for dysarthric speech have received minimal investigation.

1.7 Lombard Effect

The Lombard effect refers to the automatic and involuntary increase of speech intensity as levels of background noise increase in order to maintain comprehensible speech for the listener as well as the speaker (Ho, 1999; Zhao, & Jurafsky, 2009, Lane & Tranel, 1971). The Lombard effect has been demonstrated consistently in a number of populations however conflicting results exist regarding the extent of the Lombard effect in individuals with PD. Ho et al. (1999) found that individuals with PD find it difficult to regulate speech intensity and demonstrate an abnormal pattern of volume regulation. Individuals with PD demonstrated a reduced or absent Lombard effect when pink noise was presented as masking noise. However, Adams et al. (2008) compared speech intensity regulation in multi-talker background noise and found that individuals with PD demonstrated a consistent increase in speech intensity as background noise increased. Adams and colleagues (1992; 2005; 2006a) found that individuals with PD demonstrated a positive Lombard effect that is parallel but reduced in intensity relative to controls.

Lombard-induced speech for healthy individuals is accompanied by a hyperarticulation of phonetic segments to increase comprehensibility of spoken words. However Lombard speech in individuals with PD is only moderately associated with a significant increase in intelligibility (Zhao & Jurafsky, 2009; Adams & Lang, 1992, Adams et al., 2008). It is important to investigate the nature of intelligibility deficits in the Lombard-induced speech of individuals with PD.

1.8 Intelligibility and Parkinson's Disease

Intelligibility is almost inevitably impaired in individuals with hypokinetic dysarthria due to PD. Reduced intelligibility in PD is associated with hypophonia, monopitch, monoloudness, disordered speaking rate and imprecise articulations (Duffy, 2005). Intelligibility assessments frequently serve as an index of severity and as an overall indicator of speech adequacy (Yorkston & Beukelman, 1981). Speech distortions in dysarthric speech arise from movement impairments and do not involve language-based or word-retrieval problems. Rather, reduced intelligibility is due to a problem of information transfer, impaired articulatory function and reduction in fine motor control (Yorkston, Dowden & Beukelman,1992).

When assessing dysarthria, it has generally been assumed that the characteristics of dysarthria occur consistently across speech tasks. However, Kempler and Van Lacker (2002) suggest that dysarthria does vary across speech tasks. These researchers demonstrated various acoustic and phonetic differences in speech depending on the speech task. Listeners rated only 29% of spontaneous utterances spoken by individuals with PD as intelligible, but perceived almost 80% of repeated utterances as intelligible. As well, Kempler and Van Lacker (2002) identified a much higher rate of dysfluencies in the spontaneous utterances suggesting that dysfluencies are a prominent impediment to intelligible speech. These dramatic speech task effects suggest that an ecologically valid assessment of intelligibility in PD may require extensive and comprehensive sampling of different speech tasks, speaking conditions and social contexts.

1.9 Rationale

Hypophonia is a highly prevalent speech impairment in PD patients and depending on the nature of the hypophonia, is relatively resistant to drug and behavioral therapies. Individuals with PD report that hypophonia has a large and negative impact on their day-to-day communication, the effects of which are dramatically more apparent in increasing levels of background noise (Adams et al., 2006b). Combined with prosodic and articulatory impairments, individuals with PD appear to find it extremely difficult to maintain intelligible speech in the presence of background noise (Adams et al., 2008, Dykstra (2012), Adams, Jog (2012)**.** Unfortunately, this observation has received limited systematic attention in previous studies of PD.

Intelligibility assessments must attempt to accurately measure the difficulties that individuals with PD face in daily communication however the measurement of intelligibility in conversational speech and social contexts such as background noise have received limited attention in previous studies of PD speech. Intelligibility is typically measured using reading passages or test sentences rather than more ecologically valid speech tasks such as conversational speech. Adams et al. (2008), Dykstra (2007) and Dykstra et al., (2012) demonstrated the negative impact of multi-talker background noise on conversational speech intelligibility in individuals with hypophonia due to PD. This previous research provided a general measure of the effect of background noise on speech intelligibility but did not provide a detailed evaluation of the phonetic, acoustic or articulatory features that were responsible for the intelligibility deficit. A major focus of the present study is to obtain a more comprehensive evaluation of the speech intelligibility deficit associated with PD and to develop a detailed phonetic explanation of the effect of background noise on speech intelligibility in individuals with PD.

1.10 Objectives and Hypotheses

The primary goal of the present study was to examine the impact of background noise on speech intelligibility in individuals with PD as well as controls.

The first objective of this study was to examine the effects of quiet and loud multi-talker background noise (65dB and 75dB) on speech intelligibility in PD and control participants. It was hypothesized that both PD and control participants will show a reduction in speech intelligibility in the presence of background noise. However, it was hypothesized that the speech intelligibility of participants with PD will show a greater reduction relative to controls.

The second objective of this study was to investigate the phonetic errors associated with intelligibility deficits in individuals with PD in quiet and background noise. It was hypothesized that individuals with PD will have a greater number of phonetic errors than control participants. The present study attempted to develop a distinct phonetic error profile associated with PD speech in noise.

The third objective was to investigate the relationship between speech intensity modulation in the presence of background noise and measures of speech intelligibility. It is hypothesized that individuals with PD will modulate their speech intensity in the presence of background noise, but that this will not contribute to maintaining speech intelligibility at the level of control participants.

The fourth objective is to investigate the effect of different speech tasks (i.e. reading sentences, single word, conversation) on the speech intelligibility of PD patients in quiet and multi-talker background noise conditions. It is hypothesized that each speech task will have a different effect on speech intelligibility of participants with PD.

Chapter 2

2 Methods

2.1 Participants

Speakers. The study included 10 participants between 62 and 79 years old (M = 72.4, SD = 5.06) diagnosed with mild to moderate idiopathic Parkinson's disease who suffer from hypokinetic dysarthria and hypophonia as reported by a neurologist. There were a total of five males and five females. All participants with PD were classified between stages 1-3 of the Hoehn and Yahr System for staging Parkinsonism (Hoehn & Yahr, 1967). Participants with PD were all patients of neurologist, Dr. Mandar Jog at the Movement Disorders Clinic, London Health Sciences Centre in London, Ontario, Canada and were recruited by Dr. Scott Adams. PD participant demographic information is listed in Table 1. The study also included 10 age-equivalent healthy control subjects between 65 and 83 years old (M = 74.7, SD = 5.29). Control participants were recruited from the Retirement Research Association and the Canadian Centre for Activity and Aging at the University of Western Ontario by Professor Scott Adams and Talia Leszcz. The control participants were in overall good health with an absence of any speech, language, hearing or neurological impairments. Control participant demographic information is listed in Table 2.

Table 1. Description of PD Participants

Participant	Age	Gender	Years Since Diagnosis	Previous Occupation	PD Medication

P21	73	M	5	Bank Account Manager	Sinemet
P22	77	M	4	Engineer	Sinemet
P23	70	F	5	Supervisor	Sinemet
P24	79	M	1	Mechanic	Sinemet
P25	75	M	14	Labourer	Levodopa
P26	76	F	16	Teacher	Sinemet
P27	62	M	16	Salesman	Sinemet
P28	72	F	7	Secretary	Levodopa
P29	74	F	3	Teacher	Levodopa
P30	67	F	9	Teacher	Levodopa

Table 2. Description of Control Participants

Participant	Age	Gender	Previous Occupation
P1	83	F	N/A
P2	80	M	Techincal Director
P3	72	M	Teacher
P4	65	F	Teacher
P5	79	M	Engineer

P6	72	M	Surveyor
P7	71	M	Financial Advisor
P8	77	M	Professor
P9	72	F	Art Therapist
P10	76	M	Engineer

All participants were given a letter of information (Appendix B) about the study, along with a consent form (Appendix C) before agreeing to participate. All participants passed a 40 dB HL hearing screening and demonstrated functional reading ability. All participants were native English speakers and had not received speech therapy for at least one year prior to experimental testing. None of the participants reported previous history of a speech, language, hearing impairment or neurological disorder aside from PD. Any participant with a history of an additional neurological disorder other than PD (e.g., stroke) was excluded from the study. Participants with PD were stabilized on their anti-parkinsonian medication and were tested approximately one hour after taking their regularly scheduled anti-parkinsonian medication.

Listeners. Twenty listeners (18-30 years) were recruited to evaluate the speech intelligibility of both the Parkinson and control participant speech samples using orthographic transcription and/or correct word identification procedures. Listeners included native English speakers who were graduate students in the Faculty of Health and Rehabilitation Sciences at the University of Western Ontario. As such, university level literacy skills are assumed. All listeners were given a letter of information (Appendix D) about the study, along with a consent form (Appendix E) before agreeing to participate.

2.2 Apparatus

Each PD and control participant completed all of the experimental procedures during a single, 60-minute session in the Speech Movement Disorders Laboratory in Elborn College at the University of Western Ontario. During the experimental session, each participant was tested under three noise conditions (no noise, low-moderate (65dB) and high-moderate (75dB) multi-talker background noise) while performing four different speech tasks. During the experimental procedures, subjects were seated in an audiometric sound-proof booth (Industrial Acoustic Company) with the examiner present. Throughout the session the participant was positioned between a loudspeaker and a boom-mounted, microphone. The participant, the loudspeaker and the microphone were arranged in an equilateral triangle involving a 150 cm distance on each side (see Figure 1). The loudspeaker presented free-field multi-talker background noise (Audiotech – 4 talker noise) at two sound pressure levels (SPL), 65 dB and 75 dB. The experimenter controlled the SPL of the noise using a laptop computer that played previously calibrated files (.wav) of multi-talker noise through the output of the computer's sound card, which was connected to an audio amplifier and loudspeaker. The boom-mounted floor microphone rested on a support boom 100 cm from the floor and served as the primary source for all of the participant speech recordings. The floor microphone obtained recordings of the participant's speech in the presence of background noise. Participants wore a headset microphone (AKG – C420) situated 6 cm from their mouth to record utterances. This microphone was used to obtain a clear recording of the participant's speech without the inclusion of the background noise. The headset microphone served as a secondary recording and was used as a reference for the participants' intended conversational speech obtained during the multi-talker background noise conditions. The procedures related to the evaluation of speech intelligibility during the conversational speech task are described in a separate section. The boom-mounted floor microphone was calibrated by presenting pink noise at 70 dB 150 cm away from the loudspeaker. Two sound level meters (Realistic 33-2050) positioned at the boom-mounted floor microphone and at the participant's head were used to confirm the calibration levels. The calibration stimuli were audio recorded and used as a calibration reference for the speech recordings. The secondary headset microphone was calibrated by having each participant produce a prolonged 'ah' at 70dB SPL using a sound level meter positioned 15 cm from their mouth. Each participant was required to provide three successful 70 dB SPL calibration 'ahs'.

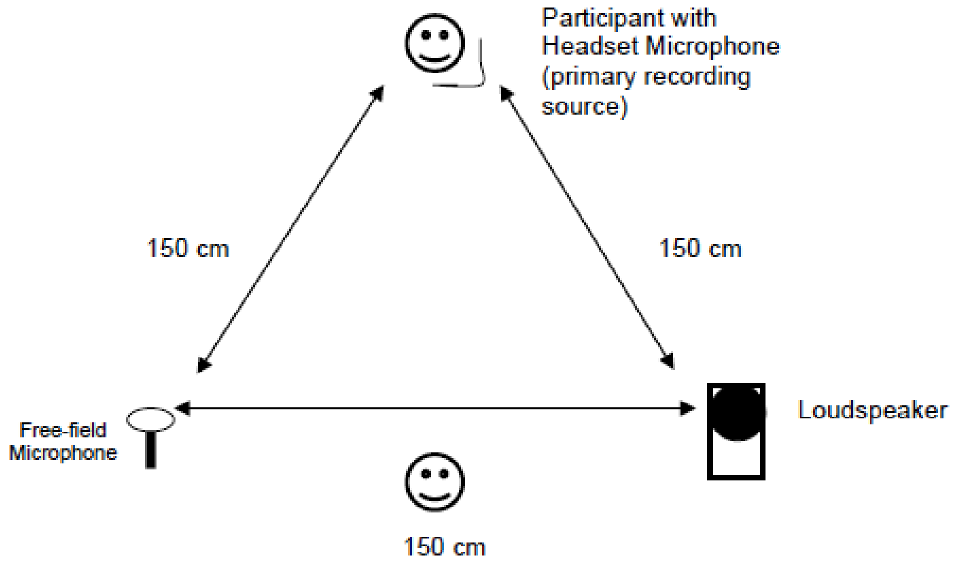

Figure 1. Experimental Setup

2.3 Materials

Background Noise. Each participant completed four different speech tasks including three standard intelligibility tests, and a conversational speech task. Each of these four speech tasks were completed in two different background noise conditions; no noise and 65 dB SPL. The conversational speech task and sentence intelligibility task were also completed in the presence of 75 dB SPL of multi-talker noise. Only two of the tasks were completed in the high level of multi-talker background noise due to difficulty with time constraints and the stress placed on participants to speak at very high intensities for extended periods of time. The multi-talker noise was obtained from a standard commercially-available sample of 4-talker noise (Audiotech – 4-talker noise). The previously calibrated multi-talker noise files (.wav) were played from the output connector of a laptop computer's sound card that was connected to an audio amplifier and loudspeaker located within an audiometric booth (Industrial Acoustic Company). This calibrated laptop-based playback system was used to set the intensity level of the multi-talker noise in the 65 and 75 dB SPL noise conditions. The order of the speech tasks and noise conditions was randomized for each participant. All of the speech tasks and noise conditions were audio-recorded.

Audio Recording. During the experimental speech tasks and noise conditions, the participants' speech was audio recorded using the boom-mounted floor microphone (Shure SM48) and the headset microphone (AKG C-420) attached via dual XLR connectors to a USB pre-amplifier system (M-Audio; Pre-mobile USB system). The USB preamplifier was attached to a laptop computer via a USB port. The audio recorder software associated with the PRAAT (version 5.2.14; Boersma & Weenink, 2011) speech analysis program was used to digitize the dual (stereo) microphone acoustic signals at 44.1 kHz and 16 bits per channel. This recording system allowed for excellent, high quality recordings of the speech and noise signals. The speech acoustic signals were analyzed and edited using PRAAT software (version 5.2.14; Boersma & Weenink, 2011). The audio signals from the floor microphone and headset microphone channels were stored in separate audio files. Each single word utterance or sentence utterance from the speech tasks was edited into a separate audio file. Approximately 10-12 utterances from the conversation sample in each noise condition were compiled together into a single file. The audio single word utterance files obtained from the floor microphone were then compiled into playlists using Alvin software (version 1.27; Hillenbrand, 2007) for presentation to the listeners. The sentence utterances and conversation audio files were compiled into Windows Media Player (version 12) for presentation to listeners.

2.4 Speaker Procedures

The Univerisity of Western Ontario Distinctive Features Differences Test (DFD) (Cheesman & Jamieson, 1996) is a feature-based test that assesses the intelligibility of 21 intervocalic consonant phonemes from the English language. Feature based testing is highly sensitive to small differences in speech perception. The test provides researchers and clinicians with an overall measure of intelligibility as well as a diagnostic measure with which to identify and estimate the frequency of specific types of consonant confusion errors made over time or in various listening conditions. The examiner presented a single nonsense word on an index card (10cm x 15cm) in the form “a**C**il” in which **C** represents one of the 21 target consonants always presented in a word-medial context. The participant was instructed to read the word aloud and then read aloud the same word in the following repeated carrier phrase “Point to the word _____, point to the word _____.” Order of target consonants was randomized among subjects and between noise conditions.

Phonetic Intelligibility Test (PIT) (Kent et al., 1989). The PIT was originally designed as a phonetically-oriented assessment of the intelligibility of dysarthric speakers. The PIT was developed as a multiple choice single word test that systematically evaluates 19 phonetic contrasts that are frequently impaired in dysarthric speakers. In the present study the PIT was administered according to the following procedures. The examiner presented a single word on an index card (10cm x 15cm) and the participant was instructed to read the word aloud and then read aloud the same word in the following repeated carrier phrase "I'll say ____ again. I'll say ____ again". The complete list of 70 PIT words and the repeated carrier phrase was read aloud by each participant in each noise condition. Two possible word orders were randomized among participants and within each noise condition.

Sentence Intelligibility Test (SIT) (Yorkston & Beukelman, 1996). The SIT is one of the most widely used tests of sentence intelligibility that has been developed for the assessment of dysarthria. The SIT is a revised, shortened version of the Assessment of Intelligibility of Dysarthric Speech (AIDS) (Yorkston & Beukelman, 1981). The SIT consists of 11 randomly generated sentences ranging in length from 5 to 15 words. One sentence at each of the 11 word lengths (5-15 words) is randomly selected from a pool of 100 sentences of each length (i.e. total sentence pool is 1100 sentences). Each participant was given three unique lists of the 11 sentences printed on a page and asked to read the sentences aloud. Each page of sentences was read in a different noise condition.

Conversational speech task. Conversations were initiated by the examiner and maintained for approximately 2 to 3 minutes in each of the three noise conditions. Participants were instructed to talk about anything they wished. Possible topics included; hobbies, family members, occupational experiences, and recent or future vacations.

2.5 Listener Procedures

The listeners were seated two feet away from a desktop computer and wore Seinheisser headphones (Model HD222.) The playback intensity of the speech stimuli was set to a medium volume level and participants were instructed not to adjust the volume. The listener to participant ratio was one-to-one in the present study (n=20) for the correct word identification listening tasks employed in the DFD and PIT. Each listener listened to both tests in both noise conditions (n = 4) from a single participant. They then listened again to one of the four tests from that same participant and one of the four tests from another participant to obtain ratings of inter and intra judge reliability. One listener completed all of the orthographic transcription of the conversation and sentence tasks. One month later, that listener judged 10% of the conversation and SIT tests a second time to obtain a rating of intra judge reliability. A second listener listened to 25% of the conversation and SIT tests to obtain a rating of inter judge reliability. Listeners were not informed if they listened to a speech sample from a disordered or normal speaker. The listening procedures and intelligibility evaluations associated with each of the four speech tasks will be described in the following sections.

2.5.1 Correct Word Identification

Twenty listeners were used to listen and judge the participants' DFD and PIT based on correct word identification. Listener intelligibility assessments were based on the participants' words in isolation, rather than in the carrier phrase. This method was selected due to concerns about listeners' time commitments and because the DFD and PIT were originally designed as single word intelligibility tests. Accordingly, a similar method was employed as described by the authors of the tests (Kent et al. 1989; Cheesman, & Jamieson, 1996). The use of the carrier phrases has potential benefits and will be discussed later.

Twenty listeners were required because the same speech stimuli are used in each administration of the PIT. This repetition of speech stimuli can cause the listener to become familiar with the test items after repeated presentations of the PIT. Listener familiarity is likely to inflate listeners' perceptions of intelligibility (Walshe et al., 2009). In order to limit this potential listener familiarity effect, a one-to-one listener to speaker ratio was used. Each listener was presented with DFD tests and PIT tests obtained from a single participant under each of the two noise conditions (no noise and 65 dB) for a total of 2 DFD tests (42 DFD words) and 2 PIT tests (140 words) per listener. Additionally, each listener re-listened to one of the four tests they initially judged and one of the four tests from a different participant in order to examine inter-rater and intra-rater reliability.

University of Western Ontario Distinctive Feature Differences Test (DFD). The listeners were required to correctly identify the target phoneme in each presentation from the list of the 21 possible consonants. The results of the DFD provided an error profile score across 21 different phonemic errors. The DFD also provides a percent intelligibility score based on the number of correctly identified target words.

Phonetic Intelligibility Test (PIT). The format of the PIT is a 70 word multiple-choice test that required the listener to identify the correct spoken word from four possible answers each differing from the target word by a specific phonetic contrast. Incorrect choices provide a phonetic error score and so the PIT provided an error profile score across 19 different phonetic errors as well as a percent intelligibility score (percent of words correctly identified by the listener). The PIT stimuli presented to the listener were randomized into two different possible word orders. This PIT randomization procedure further reduced the potential listener familiarity effect.

2.5.2 Orthographic Transcription

One of the listeners who evaluated the DFD and PIT was selected to evaluate the SIT and the conversation task for intelligibility. Additionally this listener re-evaluated 10% of the speech samples to obtain a measure of intra-rater reliability. Another listener who evaluated the DFD and PIT was selected to evaluate 25% of the participants' conversation and SIT tasks to obtain a measure of inter-rater reliability. Listeners orthographically transcribed the SIT and conversations based on the floor microphone recordings.

Sentence Intelligibility Test. The SIT listening task required the listener to orthographically transcribe each audio-recorded sentence that was spoken by the participant during the SIT task in each of the three noise conditions (no noise, 65 dB and 75 dB). The words in the transcribed sentences were compared to the words in the printed test sentences. An intelligibility score was obtained for one SIT (11 sentences) per noise condition. The number of correctly transcribed words on one SIT out of the total number of words spoken (110) was expressed as a percentage score for each participant under each of the three noise conditions.

Conversational Speech Task. A method similar to the novel approach presented by Adams et al. (2008) was used to obtain a conversational intelligibility score. The examiner transcribed approximately 10-12 sentences from each conversational speech sample in each of the three noise conditions using the audio recordings from the headset microphone. This transcription served as the reference conversational speech. The listener transcribed the same 10-12 sentences from audio-recordings obtained from the boom-mounted floor microphone. This transcription served as the tested conversational speech. Thus two transcriptions (the reference and the tested) were obtained from every conversational speech sample in each of the three noise conditions for all participants. An overall intelligibility score for each subject was calculated by comparing the transcribed words from the headset microphone (reference transcription) to those from the floor microphone recordings (tested transcription). The following formula from Adams et al. (2008) will be used,

$$\text{Intelligibility} = \frac{\text{\# of floor mic words that match headset mic. words} \times 100}{\text{\# headset mic. words}}$$

2.6 Speech Intensity

Speech intensity measures were obtained for each participant in each noise condition (no noise, 65 dB and 75 dB), on each test (DFD, PIT, SIT, conversation). The speech intensity values were measured using PRAAT software (version 5.2.14; Boersma & Weenink, 2011). Average speech intensity measures were obtained by averaging the speech intensity between the onset of voicing and the offset of voicing in each utterance. These average utterance values were then averaged within a condition in order to obtain an average speech intensity value for each condition for each participant. All speech intensity measures were based on the mouth microphone recordings that had been calibrated to a 70dB reference intensity signal that was 15cm from the participant's mouth.

2.7 Measures and Analyses

To assess the primary objective of this study intelligibility scores based on the number of words correctly identified were obtained for each participant from each test in each noise condition. A three factor repeated measures ANOVA was performed using participant group as the between groups factor with two levels (control, PD). The two within group factors included background noise (no noise, 65dB and for some tasks, 75dB) and type of intelligibility test (DFD, PIT, SIT and conversation).

In order to assess the secondary objective of this study investigating different testing procedures used for measuring speech intelligibility, a set of four separate two-way ANOVA's were performed with the participant group (PD and control) as the between group factor and the background noise (no noise, 65dB and sometimes 75dB) as the within group factor. This analysis also examined the effects of the noise conditions in more detail and allowed for the inclusion of the 75dB condition (when available) in the analyses.

The third objective of this study investigated the phonetic errors associated with intelligibility deficits in background noise. This phonetic error analysis was examined during the no noise and 65dB background noise conditions using the DFD and PIT tests. To investigate phonetic errors on the DFD a descriptive error analysis was undertaken to investigate the types of errors made by each group. To investigate phonetic errors on the PIT a series of independent t-tests were conducted to compare the results of the PD and control participants on each of the phonetic contrasts in the 65 dB noise condition.

To assess the final objective of this study, the investigation of the impact of background noise on the speech intensity, average speech intensity measures were obtained from each speaker in each of the noise conditions from each task. A three factor, repeated measures ANOVA was performed using subject group (control, PD) as the between groups factor. The two within group factors included background noise (no noise, 65dB and for some tasks, 75dB) and type of intelligibility test (DFD, PIT, SIT and conversation).

Chapter 3

3 Results

3.1 Speech Intelligibility Results

This study examined the effect of background noise on the speech intelligibility of individuals with Parkinson's disease and control participants. A three factor, repeated measures analysis of variance (ANOVA) was performed using participant group as the between groups factor with two levels (control, PD). The two within group factors included background noise and type of intelligibility test. The background noise factor had three levels (no noise, 65dB and for some tasks, 75dB). The factor related to the type of intelligibility had four levels (DFD, PIT, SIT and conversation). The results of the three-way ANOVA are presented in separate sections related to the main effects (group, noise and type of test) and the interactions. The descriptive statistics related to the intelligibility tests in the no noise and 65 dB noise conditions are shown in Table 3. The results are summarized in Figure 2. Detailed ANOVA results can be found in Appendix F.

Table 3. Overall Mean Intelligibility Scores (%)

	Intelligibility Tests							
	DFD		PIT		SIT		CONVO	
Group	NN	65 dB	NN	65 dB	NN	65 dB	NN	65 dB
Control	91.42 (8.43)	69.99 (19.34)	94.28 (4.1)	80.67 (11.17)	99.73 (.44)	89.73 (9.28)	97.08 (2.86)	85.45 (21.74)
PD	87.14 (9.54)	48.08 (22.26)	89.68 (7.52)	69.29 (23.25)	93.55 (10.22)	59.46 (34.6)	93.07 (9.94)	58.07 (35.15)

Note. NN = no noise. Standard deviation scores appear in parentheses below the means.

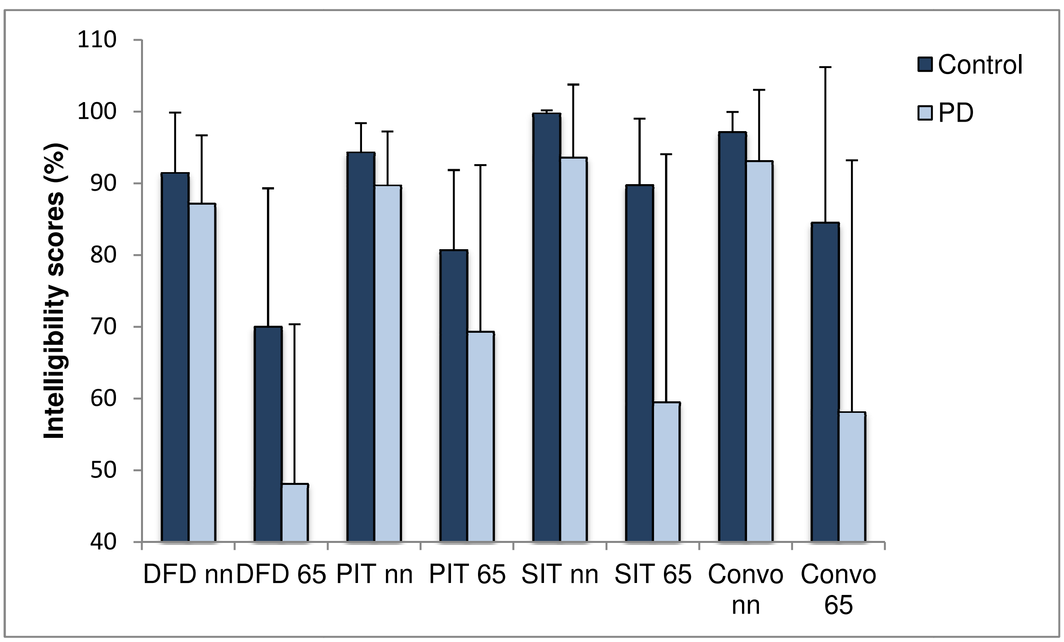

Figure 2. Mean intelligibility scores (%)

3.2 Main Effects: Group, Noise Conditions and Test Type

The main effect for group was significant, $F(1,18) = 7.445$, $p = .014$, and is illustrated in Figure 3 with associated means and standard error scores presented in Table

4. As illustrated in Figure 2 the results indicate that PD participants had lower intelligibility scores than control participants across all conditions of the study. The results related to the main effect of the noise conditions are shown in Figure 4. The descriptive statistics related to the noise conditions are provided in Table 5. The main effect of the noise condition factor was found to be significant, $F(1, 18) = 41.877$, $p = .00$. This indicates that speech intelligibility decreased significantly as the level of the background noise increased. The results for the main effect of the type of test are shown in Figure 5 with associated means and standard error scores listed in Table 6. The main effect for the type of test was found to be significant, $F(3, 54) = 4.809$, $p = .005$. This result indicates that significantly different intelligibility scores were obtained for the different types of intelligibility tests. The DFD had the lowest mean intelligibility score and the SIT had the highest mean intelligibility score.

Table 4. Mean Intelligibility Scores (%) by Group

	Control	PD
Mean	88.542	74.792
	(3.564)	(3.564)

Note. Standard error scores appear in parentheses below means.

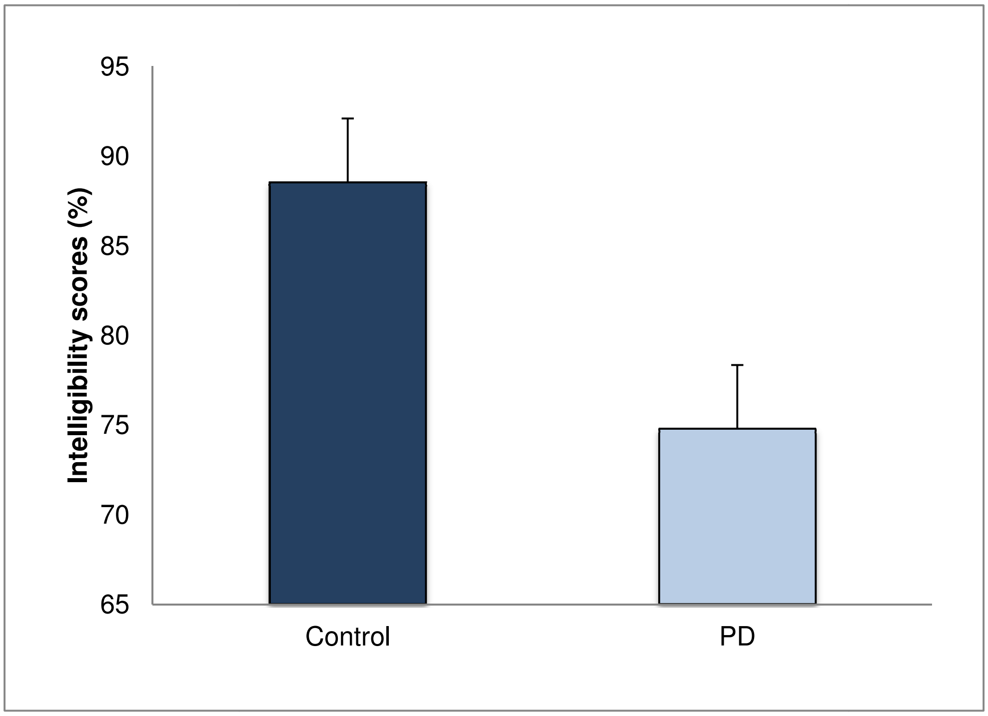

Figure 3. Mean intelligibility scores (%) by group

Table 5. Mean intelligibility scores (%) in each noise condition

	No Noise	65 dB
Mean	93.24	70.09
	(1.0)	(4.25)

Note. Standard error scores appear in parentheses below means.

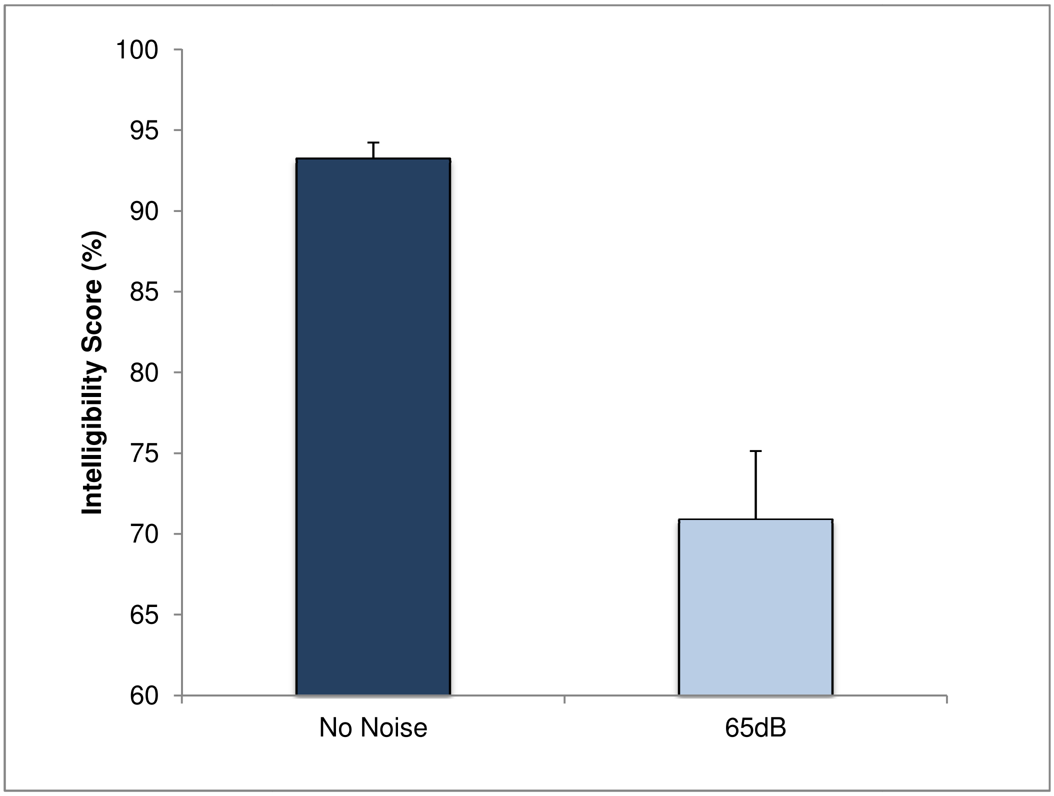

Figure 4. Mean intelligibility scores (%) in each noise condition

Table 6. Mean Intelligibility Scores (%) by Test

	Intelligibility Test			
	DFD	PIT	SIT	Convo
Mean	74.16 (3.31)	83.4 (2.56)	85.61 (3.49)	83.42 (3.7)

Note. Standard error scores appear in parentheses below means

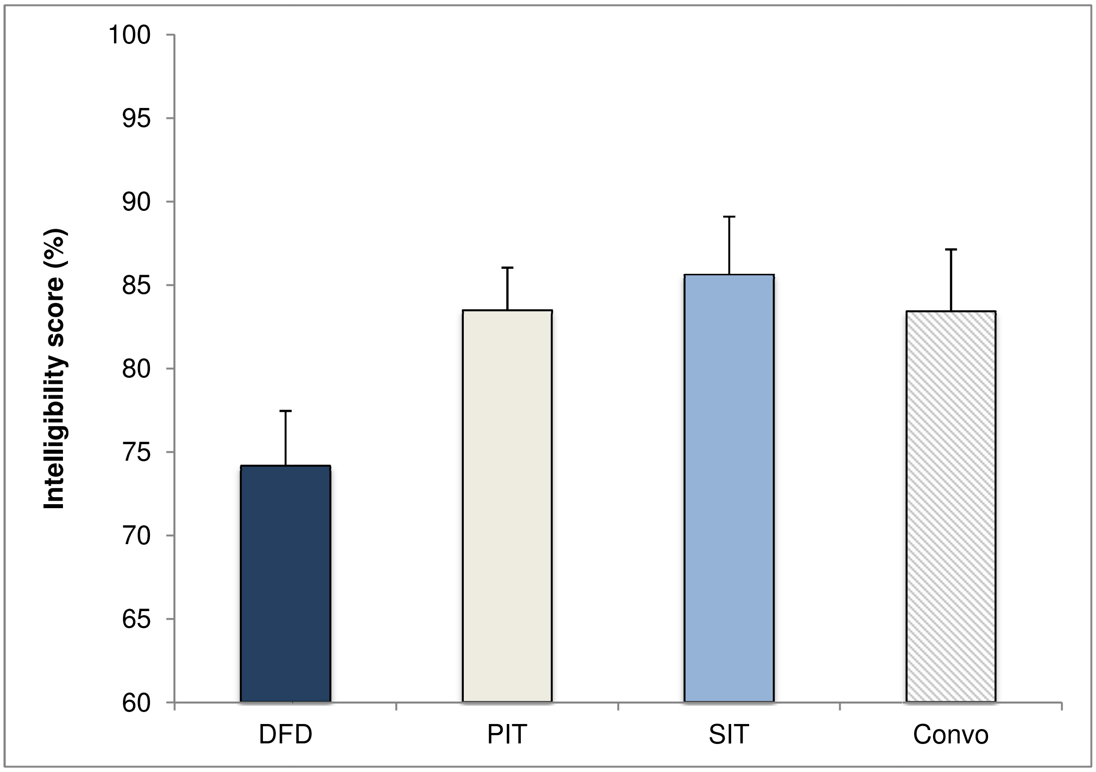

Figure 5. Mean intelligibility scores (%) by test

3.3 Interactions: Group, Noise Conditions and Test Type

The results for the noise by group interaction was significant, $F(1,18) = 6.303$, $p = .022$. This indicates that the effect of the noise conditions on intelligibility showed a different pattern in the PD participants than it did in the controls. Figure 6 suggests that as the level of the background noise increased there was a relatively greater reduction in the intelligibility scores of the PD participants than there was in the control participants. Descriptive statistics can be found in Table 7. Thus, there appears to be a greater negative slope in the intelligibility versus background noise function for the PD participants relative to the control participants.

Table 7. Mean Speech Intelligibility Scores (%) Noise by Group Interaction

Noise Condition	Control	PD
No Noise	91.42 (8.34)	87.14 (9.54)
65 dB	69.99 (29.31)	48.08 (22.26)

Note. Standard error scores appear in parentheses next to means.

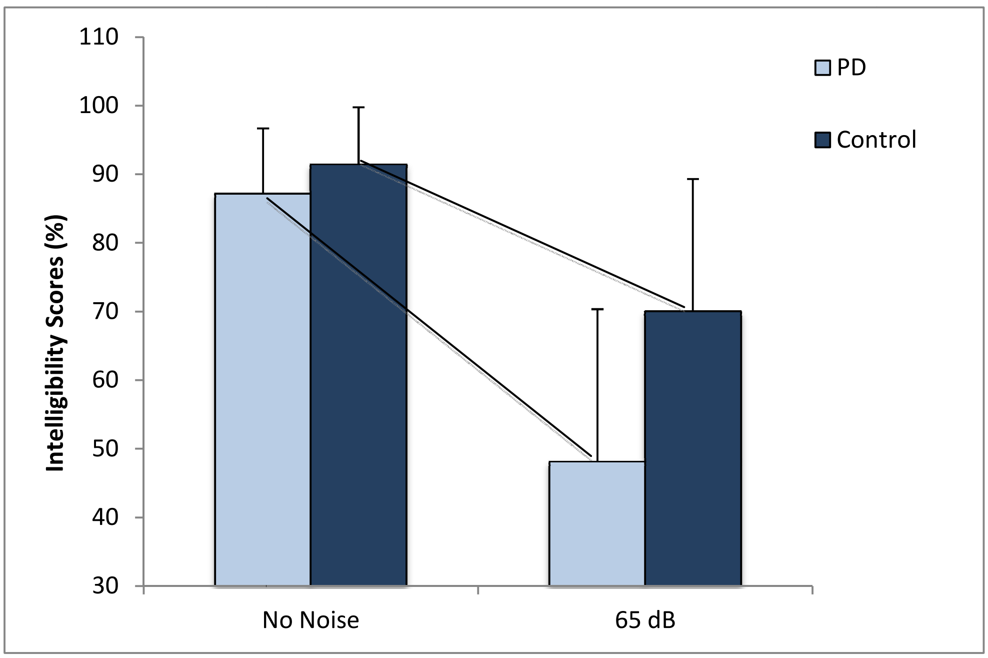

Figure 6. Effect of background noise on intelligibility scores (%)

The results for the test by group interaction was not significant, F(3, 18) = .882, *p* =.456. This indicates that both PD and control participants had a similar response pattern across all tests. Figure 7 suggests that PD participants always had reduced intelligibility scores relative to the control participants in both noise conditions regardless of the test condition. Descriptive statistics can be found in Table 8. The PD participants had significantly lower speech intelligibility scores on each test, however the pattern of change in speech intelligibility appears to be parallel across tests.

Table 8. Mean Speech Intelligibility (%) Test by Group Interaction

	Intelligibility Test			
	DFD	PIT	SIT	CONVO
Control	80.71 (4.29)	87.48 (3.63)	94.73 (4.94)	91.26 (4.77)
PD	67.61 (4.29)	79.48 (3.62)	76.5 (4.94)	78.64 (4.77)

Note. Standard deviation scores appear in parentheses beside means

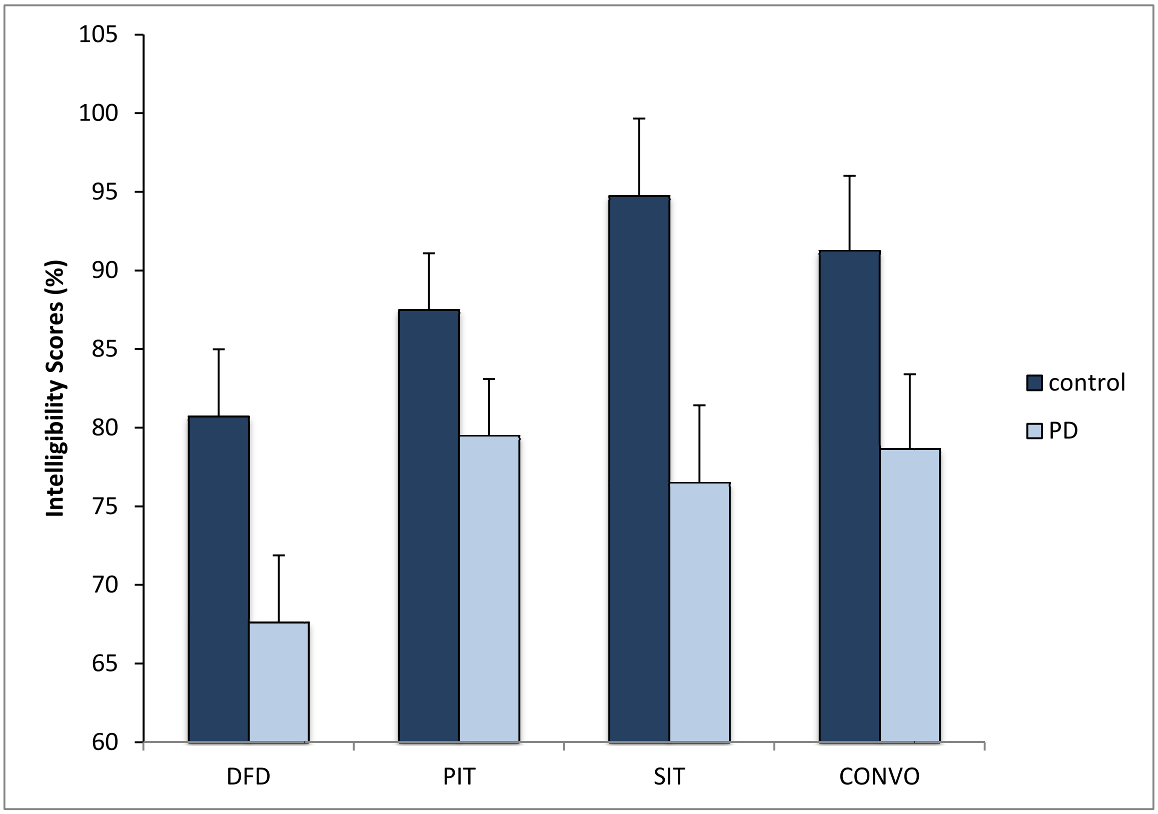

Figure 7. Effect of test on intelligibility scores (%)

The results for the test by noise interaction was significant, F(3, 54) = 2.919, *p* =.042. This indicates that the noise conditions had different effects on the results of the four intelligibility tests. For example, Figure 8 suggests that the change from the no noise to the 65 dB noise condition produced a greater reduction in the intelligibility scores for the DFD test than it did on the other 3 intelligibility tests. Descriptive statistics can be found in Table 9.

Table 9. Intelligibility Scores (%) Test by Noise Interaction

	Intelligibility Test			
Noise Condition	DFD	PIT	SIT	CONVO

No Noise	89.38 (8.99)	91.98 (6.35)	96.64 (7.72)	95.08 (7.41)
65 dB	59.03 (23.19)	74.98 (18.7)	74.59 (29.14)	71.56 (31.72)

Note. Standard deviation scores appear in parentheses beside means

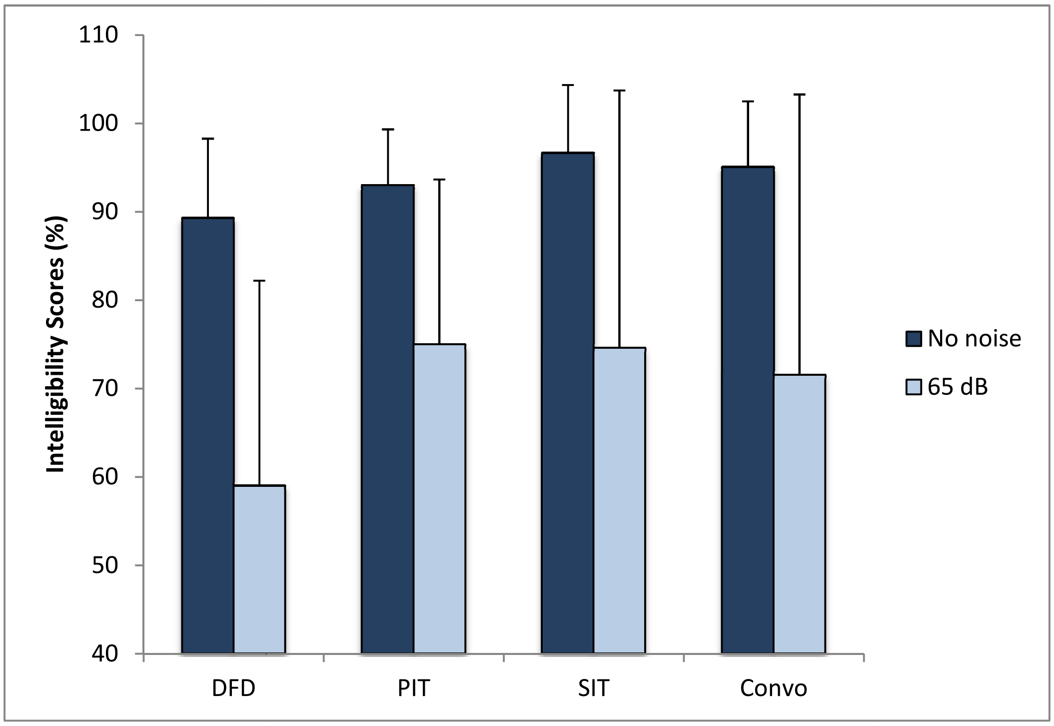

Figure 8. Effect of background noise on intelligibility scores (%)

The three-way interaction involving the group, noise and test factors was not significant, F(3, 54) = 1.567, p =.208.

3.4 Additional Analyses Involving the Extra 75 dB Noise Condition

In order to examine the effects of the noise conditions in more detail and to allow for the inclusion of the 75dB condition (when available) in the analyses, a set of four separate two-way ANOVA's were performed. This included a separate two-way

ANOVA for each intelligibility test. Detailed ANOVA results can be found in Appendix G.

Each two-way, repeated measures ANOVA included the participant group as the between group factor and the background noise as the within group factor. The group factor had two levels (PD and control) and the background noise factor had two or three levels (no noise, 65dB and sometimes 75dB). Two of the tests (DFD and PIT) were performed in two noise conditions (no noise and 65dB) and while the conversation task and SIT were performed in three noise conditions (no noise, 65dB and 75 dB). The results of the two-way ANOVAs for each test are presented in separate sections.

3.4.1 DFD

The DFD test investigated single word intelligibility of 21 non-sense words in two noise conditions (no noise, 65 dB). The descriptive statistics related to the DFD test are shown in Table 10. The results for the DFD test are summarized in Figure 9. The main effect of group was significant, $F(1,18) = 4.648$, $p = .045$. This significant main effect indicates that speech intelligibility scores were lower for the PD participants than the control participants. The main effect of noise was also significant, $F(1,18) = 62.674$, $p = .000$. This indicates that the introduction of 65dB of background noise resulted in a reduction in the DFD intelligibility scores. The interaction between noise condition and group was significant, $F(1, 18) = 776.249$, $p = .033$. This finding indicates that there was a different pattern in the effects of the background noise on the intelligibility of PD and control participants. More specifically, it appears that as the level of the background noise increased, from none to 65db, there was a relatively greater reduction in the intelligibility scores of the PD participants than there was in the control participants.

Thus, there appears to be a greater negative slope in the intelligibility versus background noise function for the PD participants relative to the control participants.

Table 10. DFD intelligibility scores (%)

Noise condition	Control	PD
No Noise	91.42 (8.34)	87.14 (9.54)
65 dB	69.99 (19.32)	48.08 (22.26)

Note. Standard error scores appear in parentheses next to means.

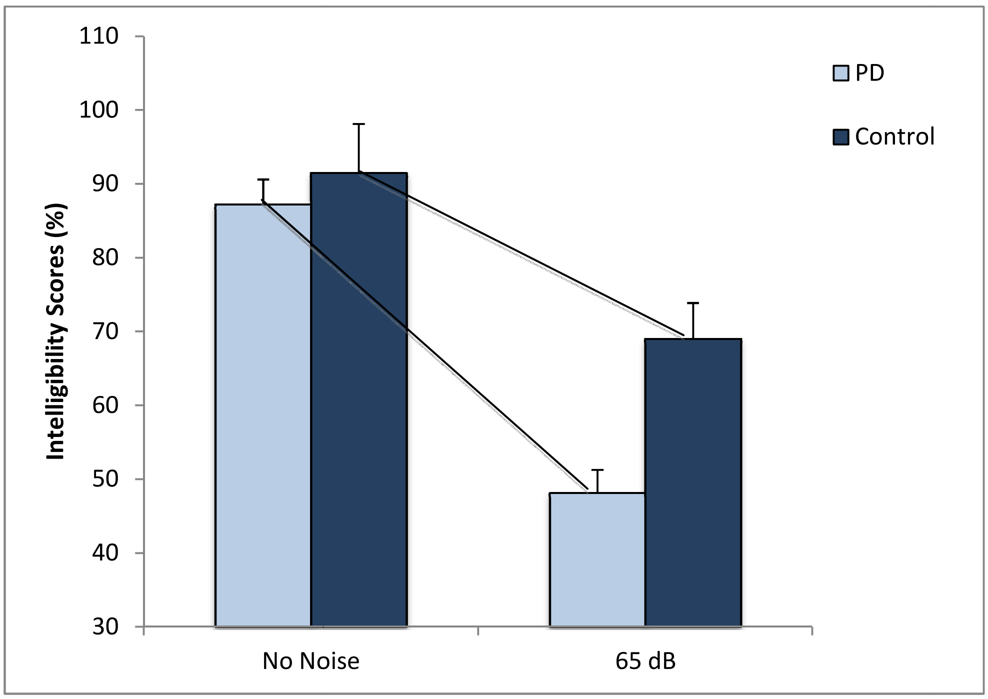

Figure 9. Effect of background noise on DFD intelligibility scores (%)

3.4.2 PIT

The PIT test investigated single word intelligibility of 70 monosyllabic English words in two noise conditions (no noise, 65 dB). The descriptive statistics related to the PIT are to shown in Table 11. The results for the PIT are summarized in Figure 10. The main effect of group was not significant, F(1,18)=2.43, p =.136. This non-significant main effect indicates that intelligibility scores for the PD participants are not significantly lower than control participants on the PIT. The main effect of noise was significant F(1,18) = 27.148, p = .000. This indicates that the introduction of 65 dB background noise resulted in a reduction in the PIT intelligibility scores. The interaction between noise condition and group on the PIT was not significant, F(1,18) = 1.079, p = .313. This finding indicates that the effect of the background noise conditions produced a similar pattern of effects on intelligibility in the PD and control participants. Overall, these results suggest that the PIT may not be highly sensitive to the effects of 65dB multi-talker background noise on hypophonia.

Table 11. PIT Intelligibility Scores (%)

Noise condition	Control	PD
No Noise	94.28 (4.1)	89.68 (7.52)
65 dB	80.67 (11.17)	69.29 (23.25)

Note. Standard error scores appear in parentheses next to means

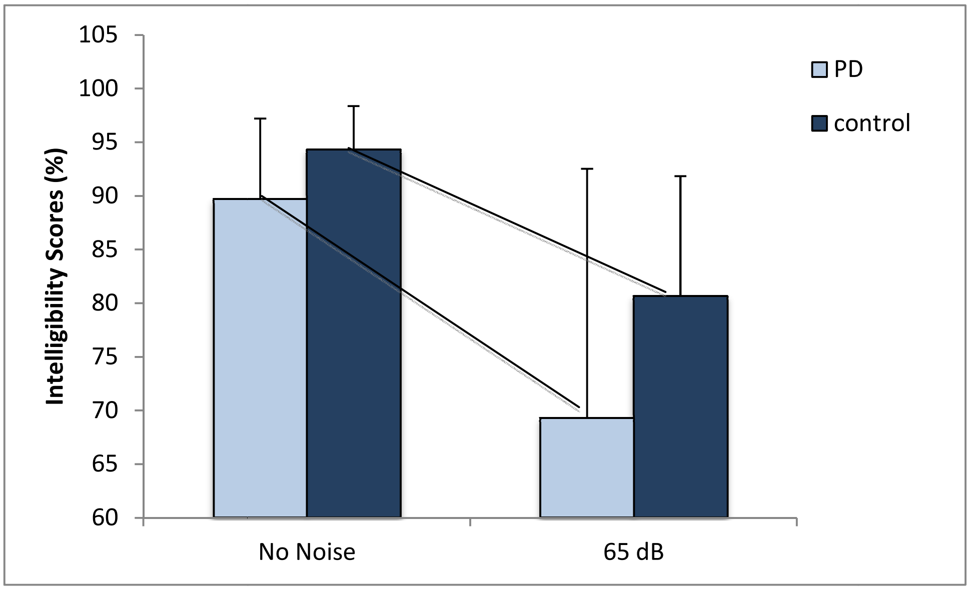

Figure 10. Effect of background noise on PIT intelligibility scores (%)

3.4.3 SIT

The SIT investigated the sentence intelligibility of 11 computer-generated sentences ranging in length from 5 to 15 words in three noise conditions (no noise, 65 dB, 75 dB). The descriptive statistics related to the SIT are shown in Table 12. The results for the SIT are summarized in Figure 11. The main effect of group was significant, F(1,18) = 12.102, p =.003. This significant main effect indicates that speech intelligibility scores were lower for PD participants than control participants. The main effect of noise was also significant, F(2,36) = 57.263, *p* = .000. This indicates that introduction of 65dB and especially of 75 dB of background noise resulted in a reduction in the SIT intelligibility scores. The interaction between noise condition and group was also significant, F(2,36)=6.98 *p*=.003. This finding indicates that there was a different pattern in the effects of background noise on the PD and control participants. More specifically, it appears that as the level of the background noise increased, from none to 65db and 75dB, there was a relatively greater reduction in the intelligibility scores of the PD participants than there was in the control participants. Thus, there appears to be a greater negative slope in the intelligibility versus background noise function for the PD participants relative to the control participants.

Table 12. SIT Intelligibility Scores (%)

Noise Condition	Control	PD
No Noise	99.73 (.44)	93.55 (10.22)
65 dB	89.73 (9.28)	59.46 (34.6)
75 dB	63.46 (28.06)	19.99 (25.5)

Note. Standard error scores appear in parentheses next to means

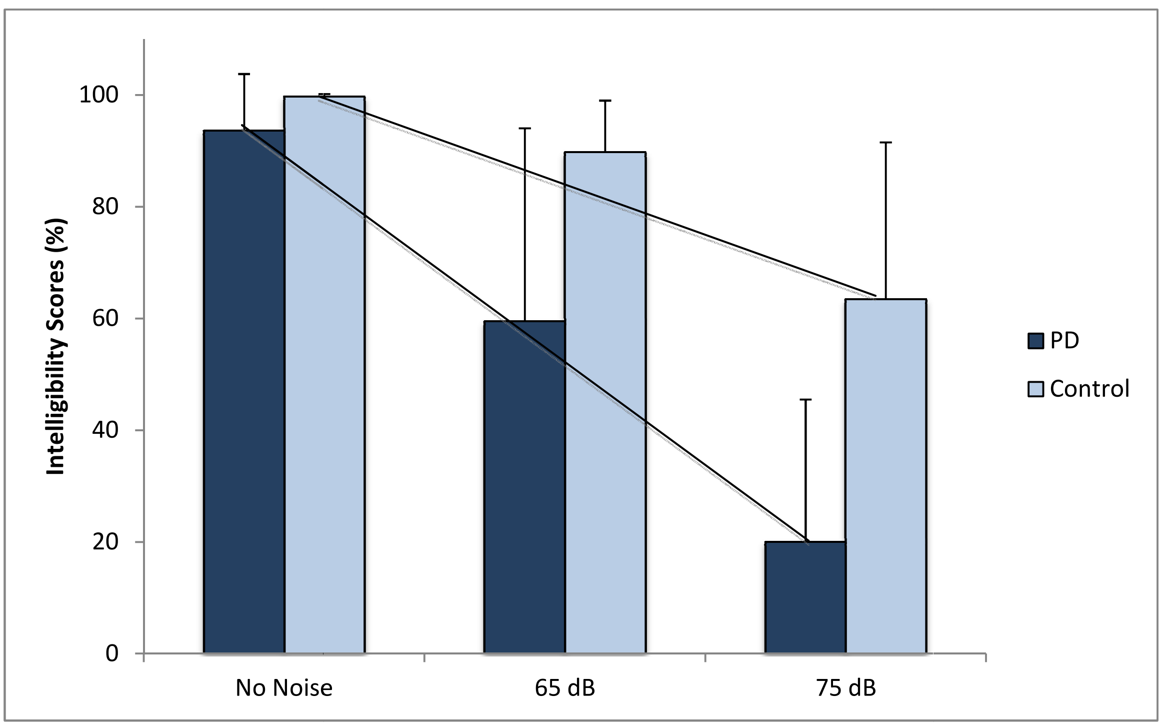

Figure 11. Effect of background noise on SIT intelligibility scores (%)

3.4.4 Conversation

The conversational intelligibility test investigated speech intelligibility in a conversational context. An average of 130 words of consecutive conversational speech obtained in three noise conditions (no noise, 65 dB, 75 dB) was used to obtain the intelligibility scores for each participant. The descriptive statistics related to these conversational intelligibility tests are shown in Table 13. The results for the conversational intelligibility test are summarized in Figure 12. The main effect of group was significant, $F(1,17) = 5.564$, $p = .031$. This significant main effect indicates that speech intelligibility scores were lower for PD participants than in control participants. The main effect of noise was also significant, $F(2,34) = 36.243$, $p=.000$. This indicates that the introduction of 65dB and especially of 75 dB background noise resulted in a reduction in the conversation intelligibility scores. The interaction between noise conditions and group was also significant, $F(2,34) = 4.568$, $p=.017$. This finding indicates that there was a different pattern in the effects of the background noise on the PD and control participants. Specifically, it appears that as the level of the background noise increased, from none, to 65db and 75dB, there was a relatively greater reduction in the conversational intelligibility scores of the PD participants than there was in the control participants. Thus, there appears to be a greater negative slope in the conversational intelligibility versus background noise function for the PD participants relative to the control participants.

Table 13. Conversation Task Intelligibility Scores (%)

Noise Condition	Control	PD

No Noise	97.08 (2.86)	92.75 (10.49)
65 dB	85.45 (21.74)	64.51 (30.35)
75 dB	68.03 (22.35)	31.63 (35.94)

Note. Standard deviation appears in parentheses next to means

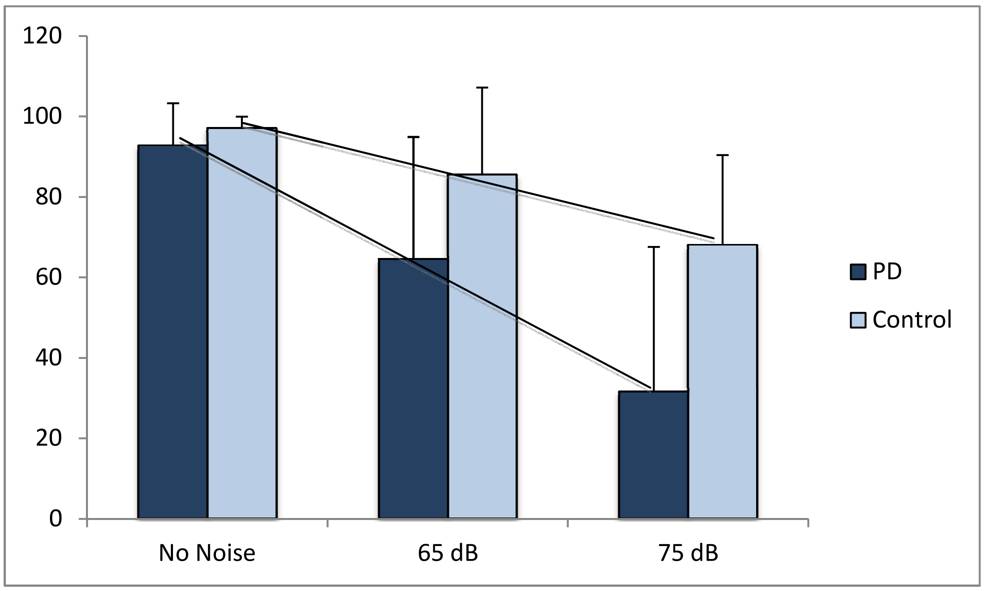

Figure 12. Effect of background noise on the Conversation intelligibility scores (%)

3.5 Reliability

To determine reliability of intelligibility measures, a portion of the data was re-analyzed by the same listener and a portion of the data was reanalyzed by a second listener. For the PIT and DFD tests, each listener reanalyzed 25% of the participant's data they originally judged, and 25% of another participant's data. For the Conversation task and the SIT, 10% of the data was reanalyzed by the original listener and 25% of the data was analyzed by a second listener. A bivariate correlation analysis revealed high intrajudge reliability for measurement of speech intelligibility ranging from .954 - .998 and high interjudge reliability ranging from .737 - .973. Table 14 summarizes the results of the correlation analyses used to obtain inter-judge and intra-judge estimates of reliability. These correlation coefficients demonstrate overall good reliability between and within judges for speech intelligibility.

Table 14. Inter and Intra-Judge Reliability

Pearson Correlation Coefficients		
	Inter-judge	Intra-judge
DFD 65 dB	.962 p = .01	.954 p = .01
PIT 65 dB	.737 p = .05	.980 p = .01
SIT (across no noise, 65 dB and 75 dB)	.973 p = .01	.998 p = .05
CONVO (across no noise, 65 dB and 75 dB)	.930 p = .01	.989 p = .05

3.6 Phonetic Error Analysis

A secondary objective of this study was to investigate the phonetic errors associated with intelligibility deficits in individuals with PD. This phonetic error analysis was examined during the no noise and 65dB background noise conditions using the DFD and PIT tests. A descriptive error analysis was undertaken to investigate the types of errors made by each group. The DFD was used to examine 21 different English consonant sounds. The DFD was analyzed to determine which consonant sounds were most frequently confused. While there was a fair bit of inconsistency in the types of errors that were made, certain types of errors occurred more frequently and it was clear that certain sounds, specifically voiced and voiceless alveolar plosives, nasals, approximants, voiceless bilabial plosives, voiceless alveolar plosives and glottals were more likely to be confused. Each occurrence of a type of error was tallied to obtain the number of times a certain sound was confused or in error. This data is presented in Figure 13. The number of errors that occurred for the DFD test can be found in Table 15. A chart containing number of errors for all 21 consonant sounds can be found in Appendix H. The analysis of errors from the DFD serves as a preliminary analysis to understand some of the processes that are causing the underlying deficits in PD speech.

Table 15. Number of DFD Consonant Errors (65 dB Noise Condition)

	til	shil	dil	hil	nil	kil	lil	mil	pil	ril	vil
PD	9	8	7	7	7	6	6	6	6	6	6
Control	6	4	3	2	4	2	4	7	2	1	5

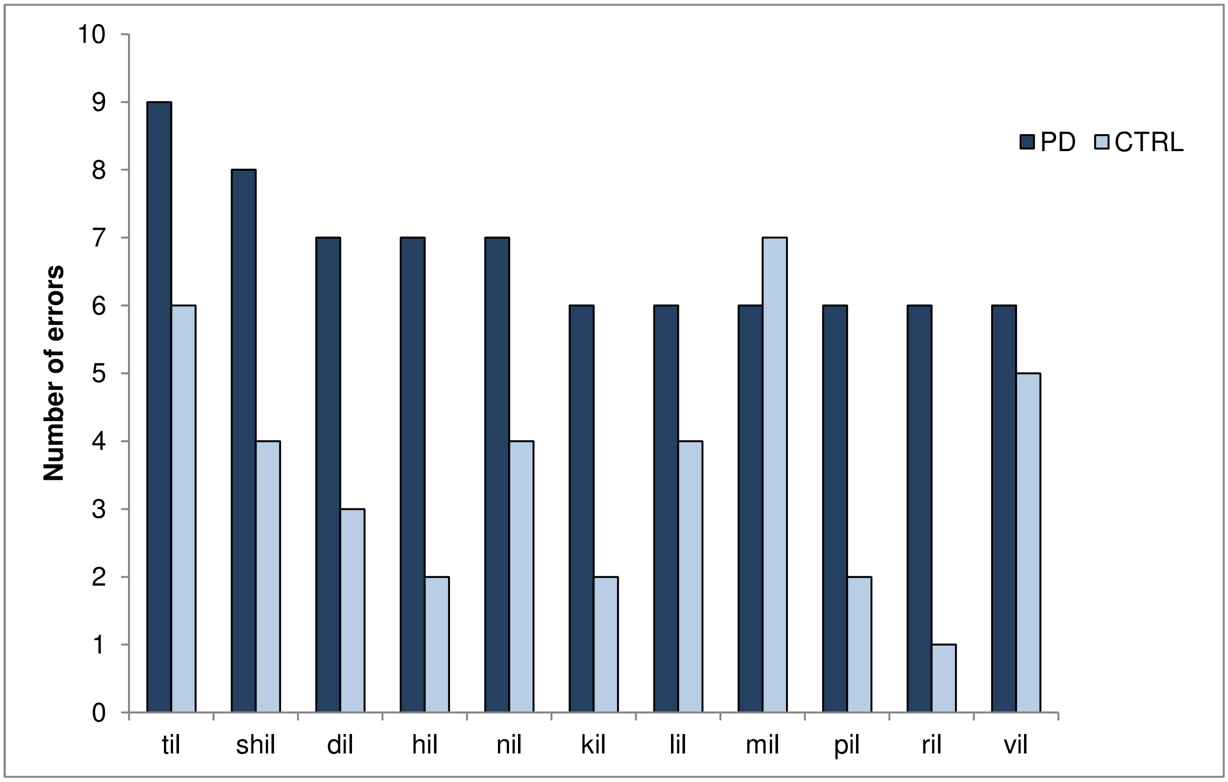

Figure 13. Number of times a sound was in error on the DFD (65 dB)

The PIT was used to examine 19 phonetic contrasts related to some of the most common types of phonetic errors in dysarthria. A detailed explanation of the 19 phonetic contrasts can be found in Appendix I. In addition to a description of the phonetic errors, a series of independent t-tests were conducted to compare the results of the PD and control participants on each of the phonetic contrasts in the 65 dB noise condition. The t-test results and the descriptive statistics, including means and standard deviations for each phonetic contrast for each group can be found in Appendix J. A separate analysis was undertaken to examine the seven phonetic contrasts that were the most frequently in error in the PD group. These seven most frequent phonetic contrast errors are presented in Figure 14. The proportion of errors for these seven phonetic contrasts expressed as a percentage can be found in Table 16. In order to obtain an average error rate for each group, each participant's received a percentage score based on the number of errors they made out of the total number of errors that could have occured. An average error rate was then calculated by averaging each participant's percent score.

Table 16. Average PIT Error Rate (%)

Group	Glot-null	Cons-null F	Clus-sing l*	Stop place*	Voice final	Stop-nasal	r-l*
Control	21.82	7.5	5.83	8.00	8.18	8.18	1
PD	23.64	18.75	15.00	15.00	10.91	10.91	11

Note. Explanation of phonetic contrasts can be found in Appendix I.
* *p < .05*

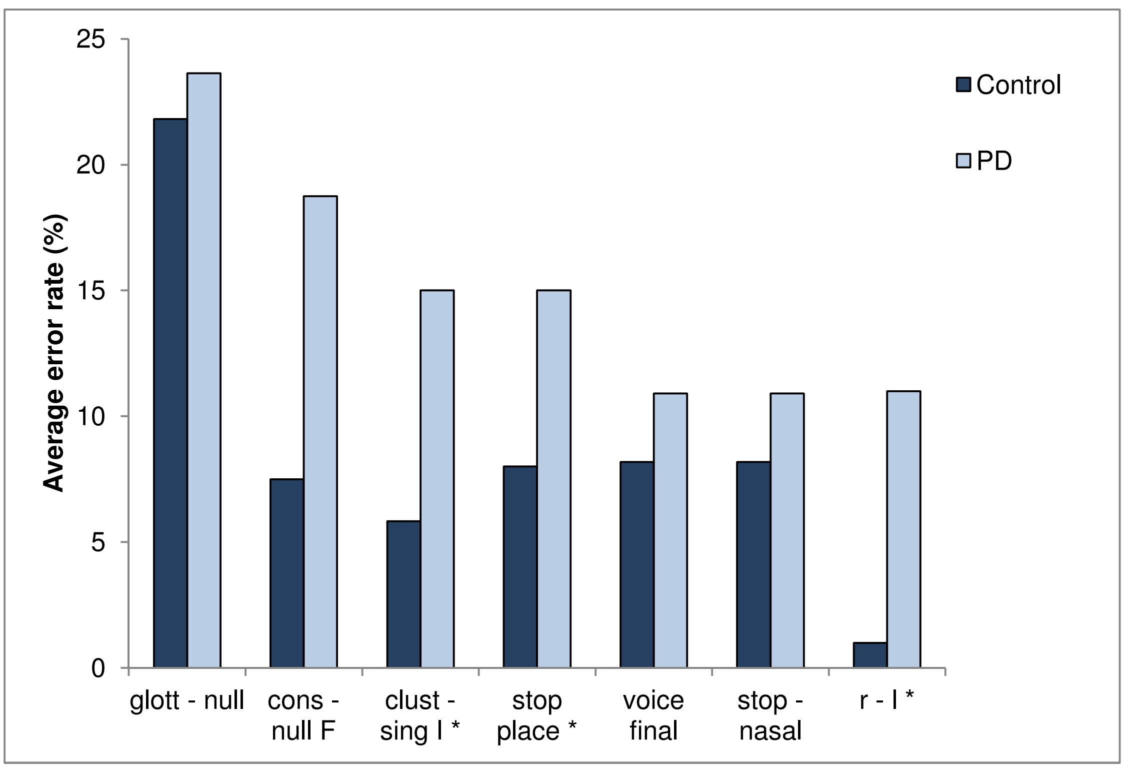

Figure 14. Group average error rate (%) on the PIT
* p < .05

While the PD group had a lower score (higher error rate) than control participants on every phonetic contrast, there was only a significant difference between PD and control participants on three phonetic contrasts. The three phonetic contrasts with significantly different intelligibility scores between the groups in the 65 dB noise condition were stop place of articulation, initial cluster singleton and r-l contrast. Stop place of articulation implies that a stop was perceived incorrectly as a stop involving a different place of articulation. This occurred more frequently for the PD participants (M = 85, SD = 9.7) than the control participants, (M = 92, SD = 7.89), $t(18) = 1.769$, $p = .047$. Initial consonant clusters were misperceived as a single consonant sound more frequently for the PD participants (M = 85, SD = 12.3) than the control participants (M = 94.17, SD = 6.9), $t(18) = 2.058$, $p = .027$. The r-l contrast was confused more frequently for the PD participants (M = 89, SD = 16.63) than control participants, (M = 99, SD = 3.16), $t(18) = 1.868$, $p = .039$.

Due to the variability in results within the PD group, and the differences in the severity of hypophonia, a further descriptive analysis was performed on the three most severely hypophonic participants in the 65 dB noise condition to investigate individual differences and to see how the individual profile predicts the group profile. The means and for all 19 phonetic contrasts for the three most severely hypophonic individuals are available in Appendix K. The pooled error rates for these three participants across all 19 phonetic contrasts in the 65 dB noise condition is presented in Figure 15. In general, the averaged phonetic profile for the three most severe PD participants corresponds very closely to the results for the entire group of 10 PD participants.

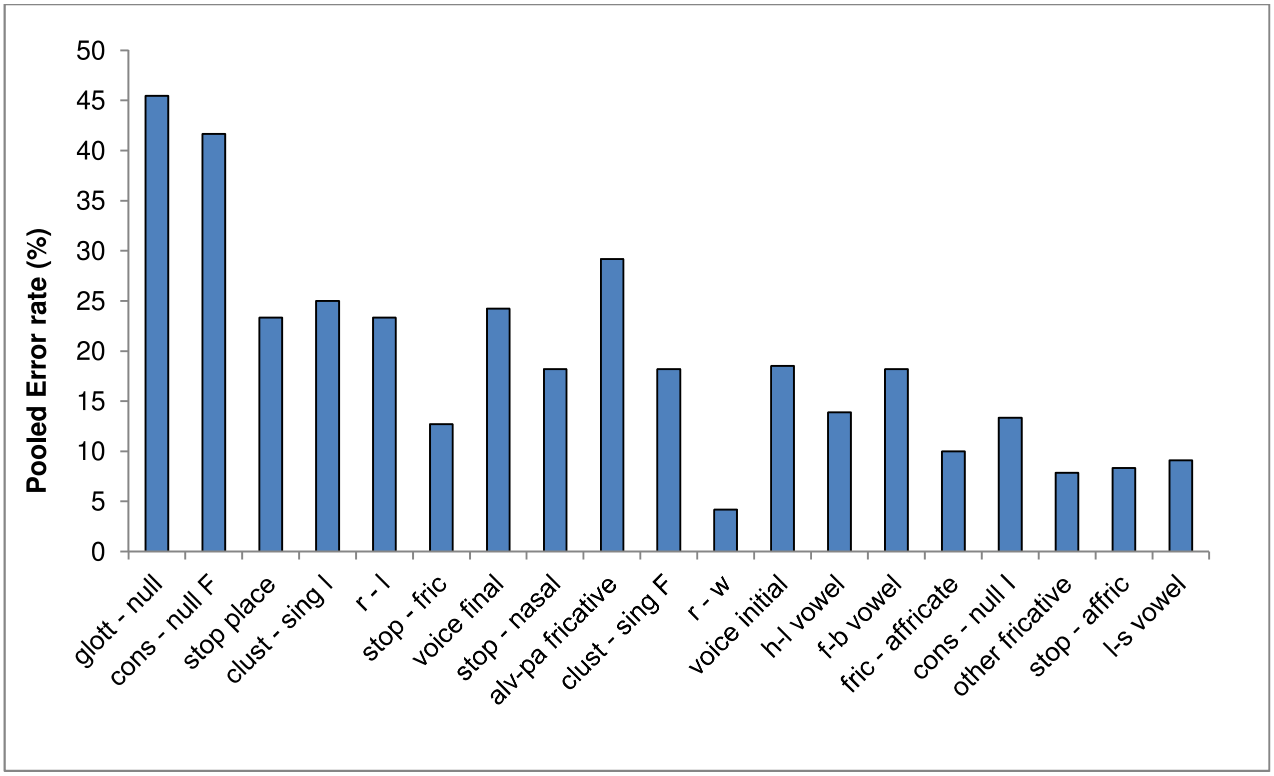

Figure 15. Error rates for the three most severe PD participants

3.7 Speech Intensity Results

A secondary objective of this study was to examine the impact of background noise on the speech intensity of individuals with Parkinson's disease and control participants. A three factor, repeated measures ANOVA was performed using participant group as the between groups factor with two levels (control, PD). The two within group factors included background noise and type of intelligibility test. The background noise factor had three levels (no noise, 65dB and for some tasks, 75dB). The factor related to the type of intelligibility had four levels (DFD, PIT, SIT and conversation). The results of the three-way ANOVA are presented in separate sections related to the main effects (group, noise and type of test) and the interactions. The descriptive statistics related to the intensity levels in the no noise and 65 dB noise conditions are shown in Table 17. The results are summarized in figure 16. Detailed ANOVA results can be found in Appendix L.

Table 17. Overall Mean Speech Intensity Levels (dB)

	Intelligibility Test							
	DFD		PIT		SIT		CONVO	
Group	NN	65 dB	NN	65 dB	NN	65 dB	NN	65 dB
Control	66.68 (6.68)	72.29 (4.89)	68.29 (4.48)	71.48 (4.09)	71.05 (6.42)	72.25 (6.42)	69.7 (4.33)	72.99 (5.39)
PD	64.8 (3.46)	70.38 (3.17)	63.98 (3.45)	69.64 (2.71)	66.87 (4.13)	69.36 (34.6)	65.54 (2.62)	68.94 (3.37)

Note. NN = no noise. Standard deviation scores appear in parentheses below means.

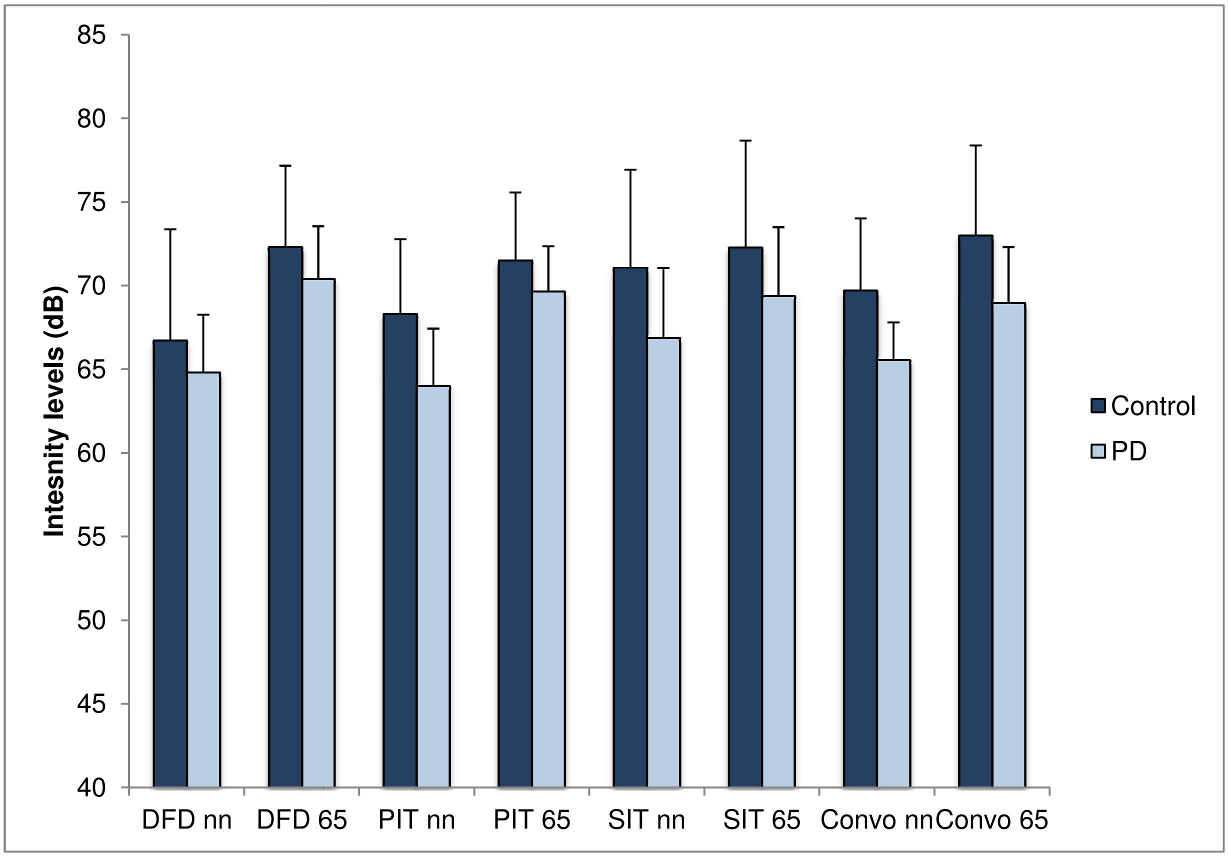

Figure 16. Overall speech intensity levels (dB)

3.8 Main Effects: Group, Noise Conditions and Test Type

The main effect of group was significant for the one-tailed ANOVA, F(1,18) = 3.577 p = .038, and is illustrated in Figure 17 with associated means and standard error scores presented in Table 18. As illustrated in Figure 17, this significant main effect was related to the PD participants having a lower speech intensity value than the control participants across all conditions of the study. The results related to the main effect of the noise conditions are shown in Figure 18. The descriptive statistics related to the noise conditions are provided in Table 19. The main effect of the noise factor was found to be significant, F(1, 18) = 93.895, p =.00. This result indicates that speech intensity increased significantly as the level of the background noise increased. The results for the main effect of the type of test are shown in Figure 19 with associated means and standard error scores listed in Table 20. The main effect for the type of test was not significant, F(3, 54) = 2.03, p =.121. This result indicates that the type of test did not affect speech intensity levels. Despite the non-significant result it is worth noting that the DFD test was associated with the lowest speech intensity values and that the SIT was associated with the highest speech intensity values.

Table 18. Group Speech Intensity Levels (dB)

	Control	PD
Mean	70.59	67.44
	(1.18)	(1.18)

Note. Standard error scores appear in parentheses below means.

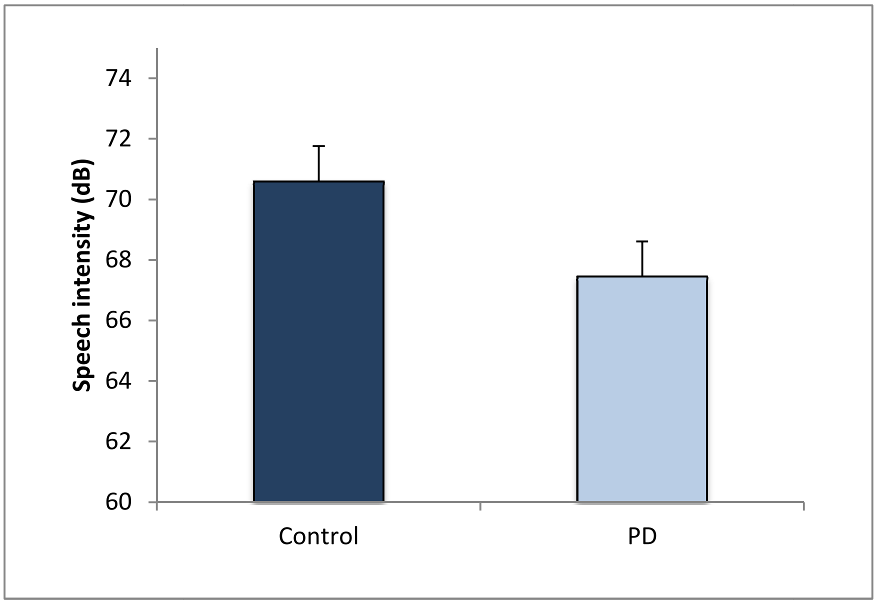

Figure 17. Group speech intensity levels (dB)

Table 19. Overall Speech Intensity Levels (dB) in each Noise Condition

	No Noise	65 dB
Mean	67.11	70.92
	(.86)	(4.85)

Note. Standard error scores appear in parentheses below means.

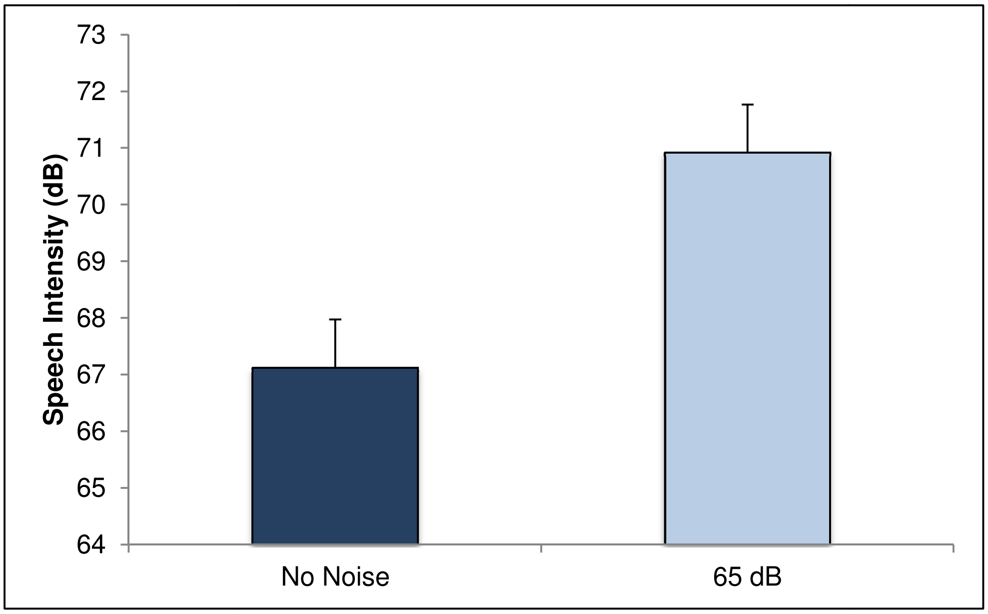

Figure 18. Speech intensity levels (dB) by noise condition

Table 20. Speech Intensity Levels (dB) by Test

	Intelligibility Test			
	DFD	PIT	SIT	Convo
Mean	68.54	68.35	69.88	69.29
	(.95)	(.77)	(1.13)	(.87)

Note. Standard error scores appear in parentheses below means

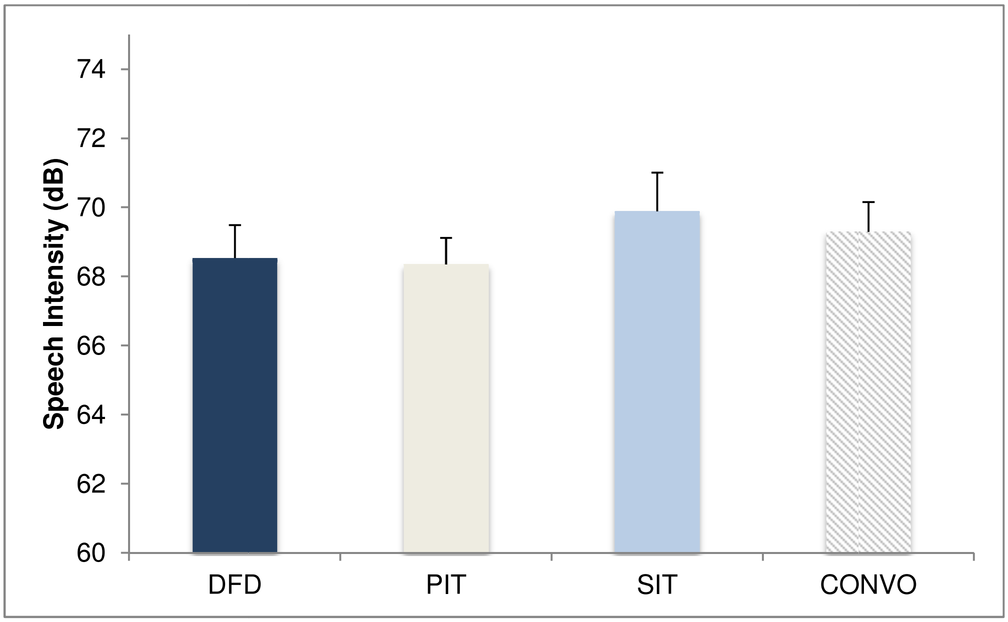

Figure 19. Speech intensity levels by test

3.9 Interactions: Group, Noise Conditions and Test Type

The results for the noise by group interaction was not significant [$F(1,18) = 1.507$, $p=.235$]. This indicates that the effect of the background noise on speech intensity showed a similar pattern in the PD and control participants. Figure 20 suggests that as the level of the background noise increased the speech intensity levels increased in a similar, parallel manner in the PD and control participants. Descriptive statistics can be found in Table 21.

Table 21. Speech Intensity Levels (dB) Group by Noise Interaction

Noise Condition	Control	PD
No Noise	72.25 (1.21)	68.93 (1.21)
65 dB	69.57 (1.21)	65.3 (1.21)

Note. Standard error scores appear in parentheses next to means.

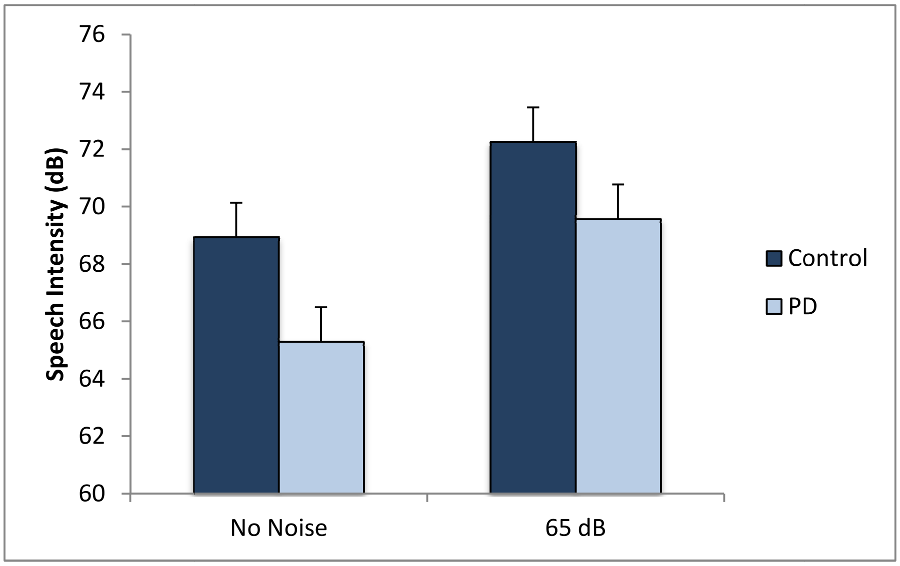

Figure 20. Effect of background noise on speech intensity levels (dB)

The results for the test by group interaction also was not significant, F(3, 18) = .890, *p* = .452. This indicates that both PD and control participants showed a similar parallel pattern in their speech intensity values across the four tests. Figure 21 suggests that the PD participants always had lower speech intensity levels relative to the control participants in both noise conditions regardless of the test condition. Descriptive statistics can be found in Table 22.

Table 22. Speech Intensity Levels (dB) Test by Group Interaction

	Intelligibility Test			
	DFD	PIT	SIT	CONVO
Control	69.48 (1.34)	69.88 (1.09)	71.65 (1.59)	71.34 (1.22)
PD	67.59 (1.34)	66.81 (1.09)	68.12 (1.59)	67.24 (1.22)

Note. Standard deviation scores appear in parentheses beside means

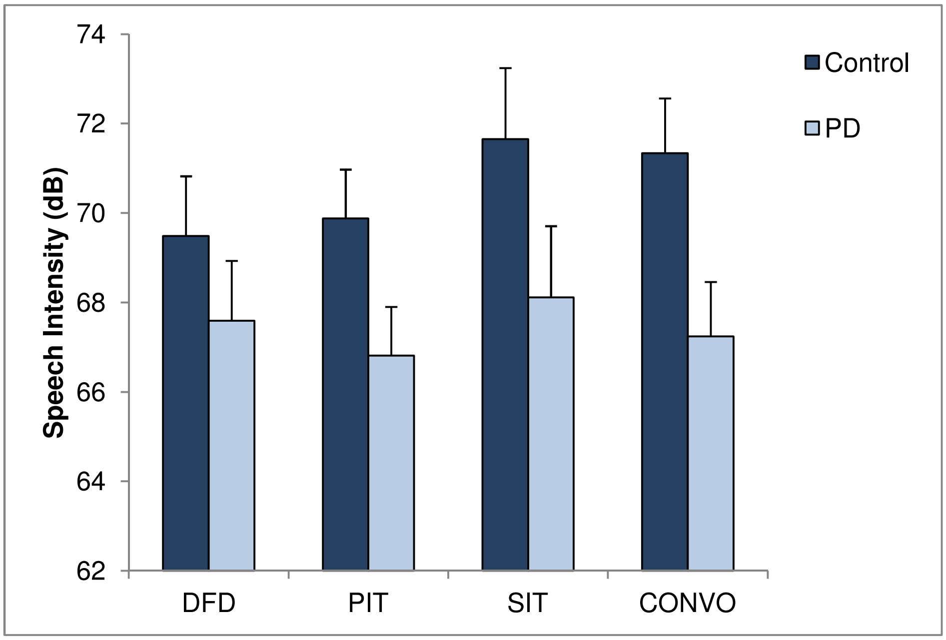

Figure 21. Effect of test on speech intensity levels (dB)

The results for the test by noise interaction was significant [F(3, 54) = 5.223, *p*=.003]. This indicates that there were different effects of the noise conditions on the speech intensity values that were influenced by which one of the four tests was examined. As the background noise increased from no noise to 65dB of noise the SIT was associated with an increase in participants' speech intensity of less than 2 dB whereas the other 3 tests were associated with a greater increase in the participants' speech intensity. The DFD test showed the highest noise-related increase in the participants' speech intensity with greater than 5dB. This can be seen in Figure 22 with associated means and standard deviation scores in Table 23.

Table 23. Speech Intensity Levels (dB) Test by Noise Interaction

	Intelligibility Test			
	DFD	PIT	SIT	CONVO
No Noise	65.74 (1.19)	66.13 (.89)	68.96 (1.14)	67.62 (.8)
65 dB	71.33 (.09)	70.56 (.78)	70.81 (1.21)	70.96 (1.01)

Note. Standard deviation scores appear in parentheses beside means

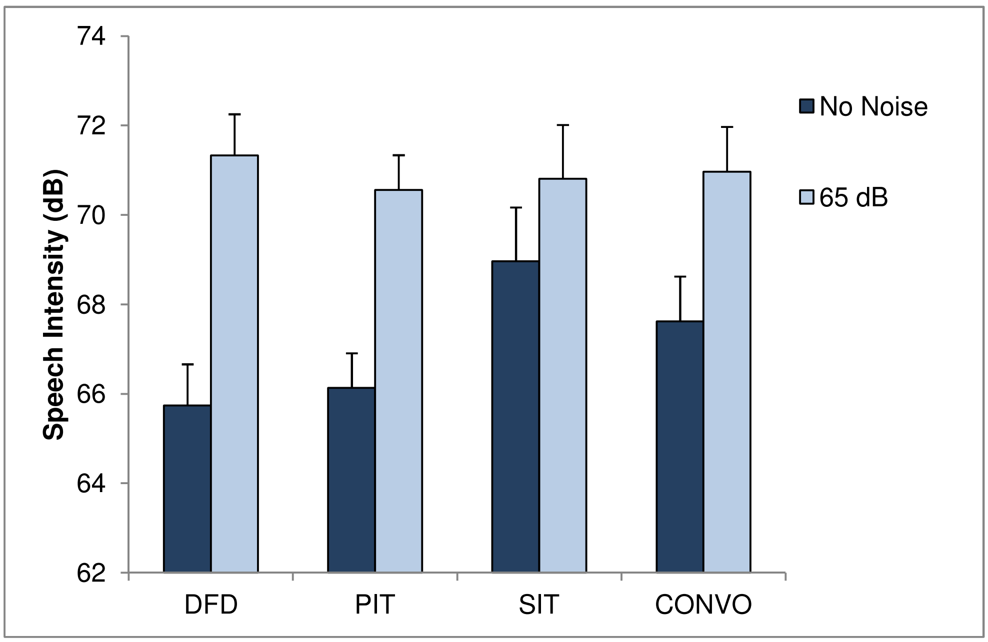

Figure 22. Effect of test on speech intensity levels (dB)

The three-way interaction involving the group, noise condition and test type was not significant [F(3, 54) = .693, p=.56].

Chapter 4

4 Discussion

The goal of the present study was to examine the impact of background noise on speech intelligibility in individuals with PD and controls. The main objectives of this study were to: 1) examine the effects of multi-talker background noise on speech intelligibility of PD and control participants; 2) examine and compare the effect of different testing procedures for measuring speech intelligibility in individuals with PD; 3) investigate the phonetic errors associated with intelligibility deficits in individuals with PD who are speaking in the presence of background noise; 4) investigate the effect of background noise and the type of intelligibility task on speech intensity levels in PD and control participants. The following sections will discuss the findings of the present study and relate these findings to previous research examining the impact of background noise on speech intelligibility and speech intensity. The limitations of the present study will also be discussed, along with clinical implications and recommendations for future research. Finally, a summary of the conclusions will be presented.

4.1 Speech Intelligibility

Speech intelligibility for both PD and control participants was investigated using two types of single word intelligibility tests and two types of sentence intelligibility tests. The single word tests were examined in two multi-talker background noise conditions (no noise, 65 dB), and the sentence intelligibility tests were examined in three conditions of background noise (no noise, 65 dB and 75 dB). In the no background noise condition, individuals with PD had intelligibility scores that were approximately 5% lower than the healthy control participants. This suggests that in relatively quiet conditions, PD participants with mild-moderate hypophonia did not demonstrate significant speech intelligibility deficits. With the introduction of background noise, individuals with PD as well as control participants demonstrated significant reductions in speech intelligibility. Of importance was the finding that there was a significant difference in how the background noise affected the intelligibility of the PD and control participants. As the level of background noise increased there was a relatively greater reduction in the intelligibility scores of the PD participants than there was in the control participants. Thus, there appeared to be a greater negative slope in the intelligibility versus background noise function for the PD participants relative to the control participants. This result is not consistent with the results of a previous study by Adams and colleagues (2008) that found a parallel reduction in intelligibility across increases in background noise. It is difficult to explain this inconsistency because very similar methods were used in the two studies; the reductions in intelligibility are also comparable across the two studies. For example, both studies found that the PD participants had conversational intelligibility scores of approximately 57-59% during the 65dB background noise condition. One difference between the two studies was that the Adams et al. (2008) study used four background noise conditions (none, 60, 65, 70 dB) while the present study used only three conditions (none, 65, 75dB). Additionally, the present study used a highest noise condition of 75dB, while the Adams et al. (2008) study used a highest noise condition of 70dB. However, it should be noted that when the 75dB noise condition was removed from the analysis (as it was for the three way ANOVA), there was still a significant difference in how the noise affected the conversational intelligibility of the PD versus control participants (i.e. a significant noise by group interaction).

Another recent study, by Dykstra et al. (2012), looked at the effect of background noise on conversational intelligibility in PD participants using a visual analogue listener rating procedure instead of the transcription procedure used in the present study. Interestingly, Dykstra et al. (2012) also found that there was a difference in how the background noise affected their PD and control participants. Dykstra et al. (2012) reported that "the conversational speech intelligibility of PD and control groups is being affected differentially with increasing levels of background noise," and that the slope lines were not parallel across noise conditions for the PD and control participants. They also noted that this interaction appears to become more pronounced in the 65 and 70 dB background noise conditions where the PD slope diverges to a greater extent than the control slope. Thus, the results of the present study appear to be very consistent with the results of the Dykstra et al. (2012) study. Interestingly, the present study found a similar pattern of results for conversational intelligibility as well as two of the three other types of intelligibility tests (DFD and SIT). This suggests that background noise causes a greater reduction in the speech intelligibility of individuals with hypophonia and PD than it does in control participants.

4.2 Speech Intelligibility Tests

The University of Ontario Distinctive Features Differences test (DFD). The DFD investigated the accuracy of consonant identification on a closed-set nonsense word test. The DFD was highly sensitive to the effects of background noise on speech intelligibility. Even without the presence of background noise, intelligibility scores on the

DFD were lower for both groups, particularly compared to the sentence and conversational level tests. In the presence of background noise, DFD speech intelligibility for individuals with PD dropped to an average of 48%, which was a significant reduction relative to the healthy control participants. In the DFD it is apparent that hypophonic speech intelligibility deficits are present without background noise, and become increasingly more apparent in the presence of background noise. This is interesting when compared to studies by Adams et al. (2008) and Dykstra et al. (2012). Both studies found a significant effect of background noise on speech intelligibility, particularly of the PD group. In addition, as previously mentioned, the Dykstra et al. (2012) study found a steeper decline in intelligibility for the PD group as background noise increased. This steeper pattern of decline in the intelligibility scores for the PD participants was also observed in the present study's results from the DFD. The DFD was not designed to test dysarthric speech rather it was developed to assess speech intelligibility in a variety of contexts and listening conditions, specifically in background noise. It is therefore not surprising that the DFD is highly sensitive to the effects of background noise. The sensitivity of the DFD and its relative ease and speed of use suggests that the DFD may be a valuable tool to investigate speech intelligibility in noise in PD and other dysarthric populations.

The low intelligibility scores on the DFD may also be influenced by the scoring method used. The DFD allows for the possibility of feature-based scoring by assessing errors in terms of the number of features that were incorrect in the response consonant versus the number of features in the correct target consonant. The intelligibility score in the current study was derived using whole-word scoring rather than feature-based scoring. This minimized the sensitivity of the DFD and resulted in a test that was more susceptible to subtle consonant confusions, which resulted in fairly low intelligibility scores in the 65 dB noise condition. Feature-based analysis of the DFD responses was employed in the phonetic error analysis and will be discussed separately.

The Phonetic Intelligibility Test (PIT). The PIT investigated 19 phonetic contrasts using a four-choice type of multiple-choice, single-word intelligibility test. Without the presence of background noise, both groups maintained moderately high levels of speech intelligibility relative to controls. Baseline intelligibility scores for the PD group were higher on the PIT than on the SIT and conversation intelligibility measures. This finding is consistent with Barreto and Ortiz (2010) who investigated different intelligibility measurement techniques in healthy participants and found that sentence transcription yielded higher intelligibility scores than single word transcription. Similarly, Yorkston and Beukelman (1978) noted that more intelligible speakers were found to obtain higher intelligibility scores on sentences rather than words.

PIT intelligibility scores for individuals with PD in the 65 dB noise condition ranged from 27% to 95%. This suggests that the PIT is sensitive to a range of dysarthric or hypophonic severities. Overall intelligibility scores were significantly reduced for both groups with the introduction of background noise. The difference in intelligibility scores for the PD and controls however, was not significant. The participants with PD had an average intelligibility score that was only about 10% less than the control participants during 65dB the background noise condition. Additionally, the interaction between noise and group was not significant, indicating that speech intelligibility of PD and control participants showed a parallel pattern across the background noise conditions. Previous research investigating the effects of background noise on speech intelligibility have found both a parallel pattern (Adams et al., 2008) and a non-parallel pattern (Dykstra, et al., 2012) of intelligibility reduction in PD and control groups with increasing levels of background noise. In the present study, this parallel pattern was only observed in the results for the PIT. The other three tests all showed the non-parallel pattern, which reflects a greater noise-related decline in intelligibility for the PD participants than the controls.

The non-significant PIT results for the comparison of the PD and control groups may be related to a variety of factors. First, this may be related to the generally higher intelligibility scores that were found for the PIT. In background noise, the PD intelligibility scores were 10-20% higher for the PIT than they were for the DFD, SIT and conversational intelligibility test. This is an interesting finding given that generally, speech in the context of sentences is scored as more intelligible than it is for single words (Beukelman & Yorkston, 1979). Miller, Heise and Leighen (1951) by contrast, demonstrated that when speech is severely degraded, as is the case in the presence of background noise, the difference in intelligibility between types of speech tasks becomes less clear. Miller and colleagues (1951) explain that the effect of task on speech intelligibility in noise is ultimately affected by the range of possible alternatives from which the listener can chose. The nature of the PIT as a closed set, four-choice, multiple-choice test implies that even if listeners are forced to guess the spoken word, their guess yields a 25% chance of being correct. Accordingly, the PIT may not be as sensitive to the effects of background noise on intelligibility deficits, and has a tendency to overestimate intelligibility (Yorkston et al. 1996). The PIT is useful for obtaining phonetic error profiles for individuals as well as for groups and provides greater insight into the underlying nature of the phonetic impairment, and may have limitations in it's ability to provide a valid measure of the severity of the speech intelligibility impairment (Blaney & Hewlett, 2006).

The Sentence Intelligibility Test (SIT). The SIT investigated sentence level intelligibility through listener transcriptions of read aloud sentences, ranging in length from 5 to 15 words. Results based on listener transcription of the SIT, revealed significant differences between control and PD participants in the two background noise conditions. This result suggests that the sentence intelligibility of participants with PD was significantly lower than controls. Specifically, the mean sentence intelligibility scores of the PD participants were approximately 20% lower overall, approximately 30% lower in the 65 dB noise condition and approximately 50% lower than control participants in the 75 dB noise condition. It is clear from the SIT, that hypophonic speech intelligibility deficits are significantly more pronounced in the presence of background noise. Previous studies investigating conversational speech intelligibility in the presence of background noise also found a significant decrease in PD speech intelligibility as background noise increased (Adams et al., 2008; Dykstra et al., 2012). The study by Dykstra et al. (2012) noted that PD and control groups were differentially affected by background noise. Interestingly, the results of the present study also found that the background noise had a different (non parallel) effect on the intelligibility of the PD and control participants. In particular, the PD participants showed a greater negative slope in intelligibility reductions relative to control participants as background noise increased from no noise, to 65 dB and to 75 dB. It appears that the SIT was consistently sensitive to intelligibility deficits in PD, and appears to be a useful tool for assessing intelligibility in the presence of background noise.

Conversation Intelligibility. The conversation task was employed to investigate speech intelligibility in the presence of background noise in a more ecologically valid context. Participants spoke for 2-3 minutes in each noise condition about familiar topics like their family, career or a recent vacation. Samples ranging in length from 100-150 words were extracted from the conversations in each noise condition and played for listeners. Results based on listener transcriptions of the conversation samples revealed significant differences between control and PD participants in the two background noise conditions. This result suggests that the sentence intelligibility of participants with PD is significantly lower than that of control participants; mean conversation intelligibility scores were approximately 15% lower overall, approximately 30% lower in the 65 dB noise condition and approximately 50% lower than control participants in the 75 dB noise condition. Adams et al. (2008) used the same method to investigate conversational speech intelligibility and found similar reductions in intelligibility scores between PD and control participants. In contrast to the Adams et al. (2008) study, the present study found a significant interaction between the noise conditions and the groups. One possible reason for this inconsistency may be that the present study employed a higher level of background noise (75dB) than used by Adams et al. (2008) (70dB). On the other hand, the pattern of results obtained in the present study are similar to those obtained in the study by Dykstra et al. (2012) who investigated PD conversational speech intelligibility in the presence of background noise using a visual analog scale to measure intelligibility. Similar to the Dykstra et al. (2012) study, the present study found that, relative to the controls, the PD participants showed a greater negative slope for the reductions in conversational intelligibility as background noise increased from no noise, to 65 dB and to 75 dB.

Intelligibility scores were reduced across all speech tasks for the PD participants relative to the controls in all noise conditions. In the no noise condition, individuals with PD did not show a significant reduction in intelligibility relative to the control participants, while maintaining intelligibility scores between 87-90%. This finding is in agreement with results reported by Bunton and Keintz (2008), who found similarly high intelligibility scores from word, sentence and spontaneous monologue orthographic transcription for individuals with PD who were speaking in quiet conditions. Results from the present study show that the introduction of background noise had a significant effect on the intelligibility of the PD participants. In addition, the greatest noise-related reduction in intelligibility was obtained for the DFD test, where individuals with PD demonstrated a reduction in intelligibility of almost 40% in the 65 dB background noise condition. The results of the PIT, another single-word intelligibility test, were associated with the highest intelligibility scores. In fact, individuals with PD did not produce intelligibility scores that were significantly different from the control participants. It is interesting to note that the two single word intelligibility tests produced significantly different intelligibility results. This is likely to be influenced by the different number of answer options in each test. By adjusting the number of selection options available to listeners, intelligibility scores can be systematically altered (Yorkston & Beukelman, 1980). Miller et al. (1951) explain that a smaller range of alternatives increases the likelihood of a correct response and that there is a direct relationship between the number of alternatives and the threshold of intelligibility for speech in noise.

Intelligibility scores for the conversation task and SIT, even in the presence of background noise, were similar to each other and reduced relative to the PIT. This is consistent with results from Yorkston and Beukelman (1978), who demonstrated that intelligibility scores for single-word multiple-choice tests are usually much higher than sentence transcription intelligibility scores. Conversational intelligibility and SIT scores were reduced by approximately 30% in the 65 dB and 50% in the 75 dB background noise condition for individuals with PD. Investigations of speech intelligibility in noise generally demonstrate that conversation tasks yield the highest scores due to contextual information available to the listener (Hustad, 2001). It is important to consider however, that hypophonia is most apparent during conversational speech tasks (Adams et al., 2006, Fox and Ramig, 1997). Results from the present study suggest that, for individuals with hypophonia, conversational intelligibility is reduced relative to single-word intelligibility in the presence of background noise. Similarly, findings by Kempler and Van Lacker (2002) assessed intelligibility in a single individual with PD and found the largest reduction in speech intelligibility on a spontaneous conversational speech task (29%) as opposed to structured speech tasks (78%). Furthermore, Kent and Kent (2000) suggest that prosodic disturbances associated with PD that contribute to reduced intelligibility are more prominent in spontaneous speech rather than in passage reading.

A study by Hustad (2001) investigated speech intelligibility of 12 individuals with dysarthria due to Cerebral Palsy (CP). They recorded speakers' production of the PIT, SIT, and of three different pre-scripted narratives. Results from their study demonstrated that for individuals with moderate dysarthria, narrative intelligibility scores were highest and there was a non-significant difference between PIT and SIT scores. The contrast in results between Hustad, (2001) and the present study, suggests that while hypophonia is a significant factor in PD reduced intelligibility, the application of background noise affects speech intelligibility in a variety of other complex ways.

4.3 Phonetic Error Analysis

Hypokinetic dysarthria is associated with a variety of articulation, prosodic, and voice impairments, all of which contribute to reduced intelligibility. Phonetic error analyses have the ability to describe the extent of speech intelligibility deficits and inform the development of a phonetic explanation of the impaired speech features responsible for the intelligibility deficit. Articulatory and acoustic speech features form the basis of perceptual recognition of speech. Some features include manner, location or place of maximum constriction and voicing (Dubno & Levitt, 1981). If one or more of these features is masked by background noise the sound may become confused with other sounds that share similar speech features. Certain phonetic contrasts contribute more towards intelligibility deficits than others and previous research suggests that differences exist in the importance of a given phonetic contrast depending on disease type, disease severity, gender and age. The descriptive error analysis used in the present study of the DFD and PIT demonstrated that specific sounds and categories of sounds were more frequently confused and contribute more towards reduced intelligibility in PD.

4.3.1 University of Western Ontario Distinctive Features Differences Test (DFD).

A sound error analysis of the DFD suggested that specific sounds were more frequently confused for the PD participants, particularly in the 65 dB noise condition. The DFD revealed that participants with PD displayed difficulties with voiced and voiceless plosives (t, d, k, p) nasals (m, n), approximants (r, l) and fricatives (h, sh). Difficulties with voiced and voiceless plosives have been previously demonstrated and are suggested to be a highly prevalent characteristic of PD speech (Weismer, 1984). Weismer (1984b) illustrated that individuals with hypokinetic dysarthria demonstrate an abnormal amount of voicing into closure and found that some of the PD subjects fully voiced approximately 45% of the voiceless stops. Weismer (1984b) also described PD problems with timing of vocal onsets and offsets and the tendency for individuals with PD to produce fricatives with an abnormal distribution of spectral energy. In particular, difficulties with glottal fricatives have been demonstrated to be a highly prevalent problem in individuals with PD as well as with other neurological impairments (Kent et al. 1990; Blaney & Hewlett, 2007). Logemann and Fisher (1981) provided a detailed description of the speech of 90 individuals with PD and reported that stops were frequently distorted and became more fricative-like, which was presumed to be the results of an inadequate narrowing of the vocal fold tract. This fricative-like distortion is considered a manner error and is referred to as spirantization. Spirantization of stops has been reported as a frequent PD articulation error in previous studies (Weismer, 1994) but is rarely a problem for healthy individuals in the presence of background noise (Miller & Nicely, 1955). Regardless, according to Bunton and Weismer (2002) spirantization does not affect correct perception of a sound by the listener.

4.3.2 Phonetic Intelligibility Test (PIT)

The error analysis of the PIT focused on the seven phonetic contrasts that were most frequently in error:1) glottal null contrast 2) final voiced consonants produced as voiceless; 3) final consonants perceived as null; 4) nasalization of plosives 5) initial consonant clusters misperceived as a single consonant sound 6) stops perceived incorrectly as a stop involving a different place of articulation; 7) r-l contrast confusion. The latter three phonetic contrasts were significantly more difficult for individuals with PD relative to the controls. (A more detailed explanation of each of the phonetic contrasts can be found in Appendix I)

Glottal null contrast. The glottal-null contrast appears to be the most frequent phonetic error on the PIT test in the present study, as well as in a number of other studies (Bunton & Weismer, 2002; Kent, 1990; Adams, 1993; Bunton ,2001). Bunton and Weismer (2002) note that the voiced-voiceless contrast and glottal versus null contrast have been studied most frequently in relation to laryngeal impairments and the impact on speech intelligibility in individuals with motor speech disorders due to Amyotrophic Lateral Sclerosis (ALS), PD and cerebrovascular accident (CV). Consistent with Bunton and Weismer (2002), the present study found the most frequent phonetic contrast error on the PIT for both groups was the glottal-null contrast. An error on this contrast occurs when an initial glottal consonant [h] is either perceived as a vowel, or a vowel is perceived as the glottal consonant. Both Neel (2009) and Kent et al. (1994) found the glottal-null contrast to be the most difficult contrast for individuals with PD.

Kent and colleagues applied the PIT to investigate intelligibility deficits in women (1992) and men (1990) with ALS. They found gender differences in the error profiles for the two groups. However, the difficulty with the glottal-null contrast was more prominent in the male group and ranked as their second most severely affected contrast. The glottal-null contrast error demonstrates the problem of poor voice quality present in certain types of dysarthria as well as the tendency for listeners to perceive dysarthric speech as a reduction of phonetic features. PD voice quality is often characterized as being breathy and harsh and is associated with the production of abnormally high levels of turbulent noise that may cause word initial vowels to be misperceived as voiceless laryngeal fricatives and visa versa. In addition, glottal fricatives are associated with a fairly low sound intensity and are thus more likely to be misperceived or completely missed by listeners.

Bunton and Weismer (2002) explain that cues for glottal perception are not well understood. The [h] is considered to be a voiceless glottal fricative that can become phonetically voiced depending on context. An acoustic analysis of this PIT error by Bunton and Weismer (2002) suggests a problem of laryngeal control that results in an early initiation of voicing and accordingly, a reduction in voice onset time (VOT). VOT refers to the time between release of the plosive and onset of voicing in the vowel and is much shorter for voiced consonants than for voiceless consonants. Jiang, Chen and Alwan (2006) illustrate that VOT duration is the most important cue for voiced-voiceless discrimination and becomes increasingly masked in the presence of background noise. Shorter VOTs increase confusions between voiced and voiceless consonants (Jiang, Chen, & Alwan, 2006). Bunton and Weismer (2002) demonstrate that reduced VOTs may be a product of aging and can be exaggerated due to neurologically impairment. This explains the high frequency of errors on the glottal-null contrast found in the present study for both PD and control participants as well as in previous studies investigating speech intelligibility deficits due to other neurological disorders (Kent, Kent & Weismer, 1990; Adams, 1993, Blaney & Hewlett, 2007).

Final voiced consonants produced as voiceless. This contrast is related to the length of the vowel preceding the final consonant. Vowels preceding voiced consonants are typically longer than those proceeding voiceless consonants. Ansel & Kent (1992) demonstrated that individuals with CP inconsistently used vowel duration to signal the voicing contrast and maintained only 54% intelligibility on this phonetic contrast. Similarly, Weismer (1984b) demonstrated that individuals with PD had longer vowel durations than control participants in the case of certain vowel groups.

Previous studies on the effect of background noise on speech intelligibility in normal speakers demonstrated that the voiced-voiceless contrast is the most robust speech feature and remains discriminable in signal-to-noise ratios of up to -15 dB (Miller & Nicely, 1955; Jiang, et al., 2006). However, in a study by Bunton and Weismer (2002), 37 of the 47 voiced target consonants were perceived incorrectly as voiceless consonants. Similarly, Blaney and Hewlett (2007) found that final consonant voicing confusions were the most difficult phonetic contrast for individuals with dysarthria due to Freidreich's ataxia. Interestingly, in normal speakers, voiced consonants are more easily identified than voiceless consonants. However, in the presence of background noise, this distinction is more difficult in word final position as opposed to word initial position (Dubno & Levitt, 1980). This could explain the non-significant difference between PD and control participants on the voiced-voiceless contrast in the present study. It appears that the application of background noise has an impact on the voice-voiceless contrast in syllable final position for both PD and control participants.

Final consonants perceived as null. Previous studies have demonstrated the tendency for listeners to perceive a reduction of phonetic features in dysarthric speech. This apparent simplification or reduction of phonetic features could also explain PD difficulty with final consonants. Another factor affecting listener perception of final consonants related to PD rate of speech. PD speech has been described as having a variable rate, frequently appearing as accelerated and being characterized by short rushes of speech (Darley et al., 1969). However the perception of accelerated speech may be a product of a reduction in acoustic contrasts (Kent & Rosenbek, 1982).

Nasalization of plosives. Confusions between stop and nasal consonant sounds has been demonstrated in studies investigating intelligibility deficits in individuals with ALS and Freidreich's ataxia (Kent et al., 1990; 1992; Blaney & Hewlett, 2007) but is infrequently an error for individuals with PD or for individuals without intelligibility deficits (Miller & Nicely, 1955, Phatak, Lovitt & Allen, 2008). A number of studies investigating consonant confusions in the presence of background noise in normal individuals found nasal consonants maintain the lowest errors rates and highest discriminability even in the presence of background noise (Phatak, Lovitt & Allen, 2008; Miller & Nicely, 1955). Reports of dysarthric speech suggest the presence of nasal articulatory errors due to velopharyngeal impairments (Ansel & Kent, 1992). Weismer (1984a) describes the tendency for individuals with PD to produce voiceless nasals that contribute to the production of imprecise consonants characteristic of PD speech. This appears to become exacerbated for PD in the presence of noise and accounts for the high rate of stop and nasal consonant confusions.

The three phonetic contrasts on the PIT that yielded significant differences between individuals with PD and the control group in the 65 dB noise condition included initial consonant clusters misperceived as a single consonant, stops perceived incorrectly as a stop involving a different place of articulation and r-l confusions.

Initial consonant clusters misperceived as a single consonant sound. Errors of consonant clusters being produced as single consonants is frequently a problem for individuals with PD but has rarely been identified as problematic for individuals with other neurological disorders (Adams, 1993; Blaney & Hewlett, 2007). This is likely due to the reduction in the range of articulatory movements and the perception of accelerated speech frequently seen in PD speech (Kent & Rosenbek, 1982). Weismer (1984a) notes that PD rapid speech is frequently characterized by a reduction in consonant duration or failure to fully articulate the consonant sound. Adams (1993) demonstrated a significant reduction of errors in this category when individuals spoke with delayed auditory feedback (DAF). The use of DAF has an effect of reducing PD rate of speech and increasing intelligence significantly.

Stops perceived incorrectly as a stop involving a different place of articulation. PD difficulty with the production of stop consonants is apparent in Weismer's (1984) finding that individuals with PD often demonstrate reduced force of movement of the articulators and the inability to make adequate vocal fold closure to produce clearly articulated stops. However, individuals with PD rarely demonstrate difficulties with stop place of articulation (Adams, 1993, Bunton & Weismer, 2001). Miller and Nicely (1955) note that place of articulation is highly susceptible to errors in the presence of background noise. Thus it appears that the presence of background noise increases the chance of errors in this category for both groups but is particularly evident for individuals with PD.

The r-l contrast confusion. Difficulties with r-l confusions are not frequently cited as intelligibility deficits in PD speech or in the speech of other neurological disorders (Kent, 1990; 1992; Adams, 1993; Bunton & Weismer, 2001). Problems with r-l contrasts have not been explained previously as a characteristic impairment of PD speech. The /r/ and /l/ sounds are classified as approximants. Production of this class of sounds requires bringing the articulators close to each other without producing audible noise. This requires a precision of the articulators that individuals with PD might lack, the results of which are exacerbated in the presence of noise.

It is apparent from the results of the present study that certain sounds are more difficult for individuals with hypokinetic dysarthria due to PD. The significance of the phonetic contrast errors suggests a distinct error profile of PD speech in the presence of background noise.

4.4 Speech Intensity

The results of this study found a significant difference in speech intensity values between the PD and control groups. Individuals with PD were on average 3 dB quieter than control participants. A 2-4 dB SPL change in speech intensity is equal to about a 40% reduction in perceived loudness. This finding is in agreement with several studies that suggest on average, individuals with PD have intensity levels 2-4 dB SPL lower than age-matched, healthy control participants (Fox & Ramig, 1997; Ho et al., 1999). In contrast, Metter and Hanson (1986) compared seven male individuals with PD to healthy age matched control participants and did not find a difference in intensity measures on a reading passage.

In the current study, the reduction in speech intensity between individuals with PD and control participants varied across tests but remained consistently around 2-4 dB SPL. The single-word PIT showed the greatest decrease in speech intensity levels between PD and control participants. This is consistent with Fox and Ramig's (2004) study that compared 29 individuals with PD and found that speech intensity was 2-4 dB lower than age and gender matched health controls across a variety of speech tasks. Some studies have noted different intensity reductions in individuals with PD subjects to control participants across speech tasks. Moon (2005) found a larger reduction in speech intensity values for conversational speech than for reading passages or memorized sentences. Similarly, Ho, Iansek and Bradshaw (2002) found a greater reduction in speech intensity relative to controls on a concurrent task condition.

Results from the present study indicate that as the level of the background noise increased the speech intensity levels increased in a similar, parallel manner in the PD and control participants. However this parallel increase was not demonstrated in the intelligibility scores. In particular, individuals with PD demonstrated the highest intelligibility scores and the lowest average intensity values on the PIT. This suggests that hypophonia is a contributing factor to reduced intelligibility; however there appear to be other relevant factors that contribute to the reduced intelligibility in PD participants.

Adams et al. (2008) demonstrated only a moderate correlation (.65) between speech intelligibility and speech intensity. As was apparent from the phonetic error analysis, there are many factors that contribute to PD reduced intelligibility including but not limited to reduced speech intensity. Future studies are required to investigate the variety of factors that affect PD speech intelligibility such as rate of speech, voice quality, nasality, prosodic variations in pitch and loudness, speech dysfluencies, and pitch and loudness declination.

4.5 Lombard Effect

To maintain adequate intelligibility in the presence of background noise it is necessary for speakers to increase the level of their speech relative to that of the noise level. The Lombard effect refers to this automatic and involuntary increase in speech intensity as levels of background noise increase in order to maintain comprehensible speech for the listener as well as the speaker (Ho, 1999; Zhao & Jurafsky, 2009, Lane & Tranel, 1971). Results from the present study indicate that individuals with PD demonstrated a positive Lombard effect and showed a lombard pattern that was parallel but reduced in intensity relative to controls. PD participants increased their intensity by 2-5 dB in the presence of background noise, but consistently remained approximately 2-4 dB below that of the control participants. This finding is in agreement with Adams and colleagues (2006) who demonstrated that individuals with PD will modulate their speech intensity in the presence of background noise, but continually demonstrated signal-to-noise ratios that were 2-3 dB lower than controls across noise conditions ranging from 50-70 dB. In contrast, Ho et al. (1999) found individuals with PD demonstrate an abnormal pattern of speech intensity regulation when conversing in different levels of background noise. These apparently conflicting results may be due to the fact that the Ho et al. (1999) study used pink noise presented through headphones while the Adams et al. (2006) study used multi-talker noise presented through a free field speaker. The present study used similar procedures to those in the Adams et al. (2006) study (multi-talker noise presented via a free field speaker) and obtained similar results. Perhaps the multi-talker background noise lends itself to the ecological validity of the study and resulted in a more reliable representation of speech performance in a natural context.

In the present study, both groups demonstrated a positive Lombard effect. The intensity increases in the present study for the control participants were significantly less than those found by Winkworth & Davis (1997) who observed an increase of around 15 dB SPL when increasing background noise from no noise to 65 dB SPL during a monologue speech task with normal participants. The discrepancy between these results and those of the present study may be related to the use of headphones in the Winkworth & Davis (1997) study. It is possible that headphones alter the perceived loudness of the background noise and disrupts the usual listener-speaker communicative process that occurs in typical free field environments. In the present study, however, background noise was presented via free-field speakers, which is more akin to a natural speaking environment. In general, the intensity results confirmed that the PD participants in the present study demonstrated reduced speech intensity, or hypophonia. It also suggests that this hypophonia is likely to have played an important role in the noise-related changes in the PD participants' speech intelligibility results.

Chapter 5

5.1 Limitations of the Current Study

Although the present study yielded many notable findings, it is important to consider certain methodological limitations. The first limitation relates to the small number of participants in the current study. A greater number of participants may have allowed for the detection of additional phonetic differences between the PD and control groups. Certain trends in types of errors and consonant confusions may have emerged as distinct patterns and more conclusive explanations of PD intelligibility deficits could have been obtained. Future studies involving a larger conversational sample may allow for a phonetic error analysis of the conversational speech.

Another aspect of subject recruitment that should be considered is the variation in hypophonia severity in the participants with PD. All PD participants were judged by the referring neurologist as being “hypophonic” and were rated as “1” or “2” on the Unified Parkinson’s Disease Rating Scale. All presented acoustically with reduced speech intensity levels, however to varying degrees. The variation in performance across individuals with PD in the present study indicates the importance of considering individual differences in speech and environment when planning treatment programs. Additionally, future studies would benefit from comparison of PD speech intelligibility based on disease severity and would provide more objective measurement of PD speech characteristics.

As well, cognitive status was not controlled for in the present study. Participants in this study did not report any cognitive impairment. Cognitive status was taken into consideration during recruitment and most of the participants were rated by the referring neurologist as having no significant cognitive impairment, however, this study did not formally assess cognitive status. Mild cognitive impairment was not considered a fundamental concern for the present study since single word reading, short sentence reading, and simple conversations were felt to have fairly low cognitive demands. On the other hand it is possible that some of the participants had a mild cognitive impairment and that this played an undetected role in the results. Future studies should consider including a cognitive assessment to determine if cognitive function plays a role in the intelligibility deficit and phonetic errors associated with hypophonia in participants with PD.

Another methodological limitation of the current study was the inability to measure all participants on all speech tasks in both the 65 dB and 75 dB noise conditions. Inclusion of the 75 dB noise condition would have reduced PD speech intelligibility dramatically, likely to intelligibility scores well below 50%. Unfortunately, the inclusion of the 75 dB noise condition would have made the testing session well over 90 minutes in length for many of the PD participants. After the first PD participants were tested it was apparent that the time of the session had to be reduced in order to avoid fatigue and participant irritation. Future studies could consider implementing additional 70 and 75 dB noise conditions in a more limited experiment that involves only one or two types of intelligibility tests. For example, it would be interesting to examine the PIT in 65dB, 70dB and 75dB of background noise in order to obtain a more detailed analysis of the effects of background noise the phonetic errors of PD participants

5.2 Future Directions

Intelligibility relates to the acoustic characteristics associated with PD speech in background noise. It would be interesting and useful to acoustically analyze the present data and explore the relationship between phonetic errors and their acoustic correlates. Future research towards developing a model of speech intelligibility in PD should examine how specific changes in production are reflected in the acoustic signal and how this affects perception of the sound and ultimately overall intelligibility. Additionally, future studies could take advantage of the carrier phrase recordings obtained from the present study. This would allow one to investigate the different effects of background noise on a word in isolation versus in a sentence.

A separate study examining speech intensity in more detail in background noise in individuals with PD would also be helpful. In the current study, speech intensity values were based on average speech intensity of the utterances. Intensity decay across the utterance was not examined in the present study. However, intensity decay across an utterance span has been noted frequently as a feature of the speech deficit associated with PD. It would be interesting to compare speech intensity estimates that quantify speech intensity declination over an utterance or test. Comparison of the first sentence to the second sentence carrier phrases on the present study would enable an investigation of intensity declination across the utterance. In addition, the signal-to-noise ratio values for the utterances were not obtained. Previous studies of PD and of normal speakers have demonstrated the importance of maintaining a specific signal-to-noise level in order to achieve adequate intelligibility. It would also be interesting to investigate how the signal-to-noise ratio maps onto the phonetic error profile of each participant. Presumably people with PD must sustain a higher signal-to- noise ratio to maintain intelligibility and to compensate for other speech and voice characteristics that are frequently impaired in addition to speech intensity.

Future research could explore various measurement techniques relating to intelligibility measurement. In the current study, the DFD and PIT were analyzed based on correct word identification and conversational and sentence intelligibility was analyzed based on orthographic transcription. It would be interesting to see how these intelligibility scores relate to intelligibility scores derived from rating scale measurement techniques. Generally, orthographic transcription is regarded as a more objective and ecologically valid measure of intelligibility (Schiavetti, 1992). However it would be interesting to investigate how different methods of intelligibility measurement in background noise relate to one another.

5.3 Clinical and Research Implications

The results of the present study provide some significant considerations for clinical practice and research applications. It is important to recognize that the capabilities demonstrated by individuals with PD in a clinical context may not be wholly representative of their speech capabilities employed in everyday communication contexts. The measurement of a client's speech intelligibility in the presence of background noise is considered an ecologically valid and potentially useful procedure in the assessment of hypophonia in PD. The present study is consistent with previous studies that have found that individuals with PD consistently demonstrate a parallel pattern of intensity modulation to that of healthy controls in the presence of background noise. In contrast to this, individuals with PD do not show a similar or parallel pattern of deterioration in intelligibility to that of healthy controls across increases in background noise. This finding suggests that there is a complex relationship between background noise and intelligibility that may need to be systematically defined and considered in the evaluation and planning of treatment interventions for individuals with hypophonia and PD. In addition, it is likely that other complex noise-to-intelligibility relationships exist in many other types of dysarthria and that these also may need to be given consideration in the evaluation and intervention procedures.

Results from the current study clearly demonstrate the significant effect of background noise on PD speech intelligibility and provide support for further investigations of speech intelligibility in background noise in individuals with PD. Based on these results, the introduction of background noise in clinical assessment appears to have the potential to provide a better estimate of the severity of hypophonia in PD. It is clear from the current study that this provides a more realistic assessment of hypophonia in PD and is more representative of situations the individual will encounter outside of the clinic.

5.4 Summary and Conclusions

The present study investigated the effects of background noise on speech intelligibility. Speech intelligibility was measured at the single-word level, sentence level and conversational level with two or three levels of multi-talker background noise (no noise, 65 dB and 75 dB). Overall, participants showed reduced intelligibility as background noise increased. This effect was significantly more pronounced for the individuals with PD. Individuals with PD had intelligibility scores approximately 20-30% lower than controls in 65 dB of background noise and approximately 35-45% lower than controls at the 75 dB level of background noise. However, without the presence of background noise, individuals with PD exhibited intelligibility scores that were only 4-6% lower than controls. This suggests that in relatively quiet conditions, individuals with mild to moderate hypophonia do not present with severe speech intelligibility deficits and strongly suggests that clinical intelligibility testing for individuals with hypophonia and PD should be conducted in the presence of background noise (Dykstra, 2012).

Additionally, this study investigated specific phonetic errors associated with PD speech intelligibility deficits. This study provided a preliminary analysis of the types of phonetic errors produced by individuals with PD in the presence of background noise. It appears that a unique error pattern exists for PD speech in the presence of background noise. Some PD phonetic contrast errors were consistent with those of previous experiments investigating phonetic error patterns of loud speech (Neel, 2009). Some PD phonetic contrast errors were consistent with experiments investigating PD speech intelligibility as well as that of other neurological disorders without background noise (Kent et al., 1990; Kent et al., 1992; Blaney & Hewlett, 2007; Hustad, 2007, Adams, 1993). This further implicates the importance of conducting intelligibility assessments in the presence of background noise.

Overall, this study sought to examine speech intelligibility of hypophonic individuals with PD speaking in the presence of background noise. Results of this study emphasize the importance of background noise in intelligibility assessments and added potentially valuable information regarding phonetic errors patterns in the presence of background noise. Future studies are needed to investigate the phonetic errors associated with PD speech in noise in more detail as well as to further understand the relationship between hypophonia and speech intelligibility in background noise.

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Appendices

Appendix A. UWO Ethics Approval

Research Western

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Scott Adams
Review Number: 18070E
Review Level: Delegated
Approved Local Adult Participants: 80
Approved Local Minor Participants: 0
Protocol Title: Speech Intelligibility and Background Noise in Parkinson's Disease
Department & Institution: Communication Sciences & Disorders, University of Western Ontario
Sponsor:
Ethics Approval Date: July 19, 2011 **Expiry Date:** August 31, 2012
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
UWO Protocol		
Letter of Information & Consent	Patients	2011/07/28
Letter of Information & Consent	Controls	2011/07/28
Other	Recruitment Script	

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The UWO HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940

The **University** ***of*** **Western Ontario**
Office of Research Ethics
Support Services Building Room 5150 • London, Ontario • CANADA – N6A 3K7
PH: 519-661-3036 • F: 519-850-2466 • ethics@uwo.ca • www.uwo.ca/research/ethics

Appendix B. Participant Letter of Information

LETTER OF INFORMATION

STUDY TITLE
Speech Intelligibility and Background Noise in Parkinson's Disease.

PRINCIPAL INVESTIGATOR
Scott Adams, Ph.D.
Professor
School of Communication Sciences and Disorders; Clinical Neurological Sciences
University of Western Ontario

CO-INVESTIGATORS
Dr. Mandar Jog, MD, FRCPC
Director, Movement Disorders Program,
London Health Sciences Centre, University Campus and
University of Western Ontario

Dr. Allyson Dykstra, Ph.D.
Assistant Professor
School of Communication Sciences and Disorders
University of Western Ontario

Talia Leszcz
MSc. Candidate,
Health and Rehabilitation Sciences
University of Western Ontario

INTRODUCTION

This letter of information describes a research study and what you may expect if you decide to participate. You should read the letter carefully and ask the person discussing this with you any questions that you may have before making a decision whether or not to participate. This form contains important information and telephone numbers, so you should keep this copy for future reference. If you decide not to participate in this study, the decision will not be held against you and will not affect your treatment in any way.

You are being asked to participate in this research study because you are an individual with reduced speech intensity and Parkinson's disease or you are an individual who does not have Parkinson's disease or any other neurological disorder. The purpose of this study is to investigate the effect of background noise on speech intelligibility and to provide a detailed evaluation of the phonetic features responsible for intelligibility deficits.

This study will involve 80 participants. Twenty of the participants will have reduced speech intensity and Parkinson's disease. Twenty participants will not have any neurological conditions and 40 participants, with no neurological condition will serve as listeners. Information about participants will be collected from person-to-person interviews by the principal experimenter or another designated member of the research team. This will include information about the participant's date of birth, general medical history, neurological history, and speech and hearing history.

This study will involve evaluating your speech intelligibility in three noise conditions (no noise, low-moderate and high-moderate multi-talker background noise) while performing four different speech tasks. The speech tasks will include three different sentence reading tasks. The first task involves reading aloud 70 sentences (each 8 words in length) and the second task involves reading aloud 21sentences (each 7 words in length). A third sentence reading task will include 11 sentences ranging in length from 5-15 words. The fourth speech task involves conversation. A short conversation will be elicited between you and the experimenter for 2-3 minutes on familiar topics such as hobbies, family members, occupational experiences, vacations, favorite childhood experiences, etc. For the sentence reading tasks you will be shown a sentence and asked to read what is presented to you. The levels of background noise used in this study are 65 and 75 dB SPL, which are not excessive levels and will not cause any hearing damage (65 dB SPL is comparable to moderate cafeteria noise, and 75 dB SPL is comparable to busy traffic noise). During all of the conditions, you will wear a head-set microphone that will record your speech on a laptop computer. After you complete the experimental trials, we will conduct a standard hearing assessment. During the standard hearing assessment, you will hear a variety of sounds at different intensities and frequencies. If you agree to participate you will be asked to come one time to Elborn College at the University of Western Ontario for testing. It is anticipated that the total time for this experiment and the hearing test will be no more than 60 minutes.

The experimental procedures will require very little physical effort, and there is no known discomfort or risk involved in performing them. You will be seated in a comfortable chair throughout the procedures and you will be given rest breaks approximately every five minutes or more frequently if required.

The procedures that will be used during this study are experimental in nature and will not provide any direct benefit to the participant's medical condition, however, it is anticipated that results from this study may provide important information about the nature of the intelligibility deficits in individuals with Parkinson's disease. Financial compensation will not be provided upon completion of this study. Free parking will be provided while you are visiting the lab at Elborn College.

Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions, or withdraw from the study at any time with no effect on your future care.

All of the information obtained in this study will be held in strict confidence. Your name and any identifying information will be removed from the data. If the results of the study are published, your name will not be used and no information that discloses your identity will be released or published.

Throughout the study, all confidential information will be preserved in a locked filing cabinet in the Principal Investigator's laboratory at Elborn College, University of Western Ontario.

If requested, you will be provided with a copy of any publication related to the results of this study when it becomes available.

If you have any questions or would like additional information about this study, please contact Professor Scott Adams at the School of Communication Sciences and Disorders, Elborn College, University of Western Ontario, London, Ontario, N6G 1H1 [redacted]

If you have any questions about the conduct of this study or your rights as a research subject you may contact Dr. David Hill, Scientific Director, Lawson Health Research Institute, at [redacted].

If you agree to participate in this study, please sign the consent form on the next page.

Sincerely,

Scott Adams, Ph.D.

Professor

Appendix C. Participant Consent Form

CONSENT FORM

STUDY TITLE
Speech Intelligibility and Background Noise in Parkinson's Disease

PRINCIPAL INVESTIGATOR
Scott Adams, Ph.D.
Professor
School of Communication Sciences and Disorders; Clinical Neurological Sciences
University of Western Ontario

CO-INVESTIGATORS
Dr. Mandar Jog, MD, FRCPC
Director, Movement Disorders Program,
London Health Sciences Centre, University Campus and
University of Western Ontario

Dr. Allyson Dykstra, Ph.D.
Assistant Professor
School of Communication Sciences and Disorders
University of Western Ontario

Talia Leszcz
MSc. Candidate,
Health and Rehabilitation Sciences
University of Western Ontario

I have read the Letter of Information (have had the nature of the study explained to me), and I agree to participate. All questions have been answered to my satisfaction.

____
Signature of Research Subject Printed Name Date

____
Signature of Person Obtaining Consent Printed Name Date

Appendix D. Listener Letter of Information

LETTER OF INFORMATION

STUDY TITLE
Speech Intelligibility and Background Noise in Parkinson's Disease.

PRINCIPAL INVESTIGATOR
Scott Adams, Ph.D.
Professor
School of Communication Sciences and Disorders; Clinical Neurological Sciences
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University of Western Ontario

INTRODUCTION

This letter of information describes a research study and what you may expect if you decide to participate. You should read the letter carefully and ask the person discussing this with you any questions that you may have before making a decision whether or not to participate. This form contains important information and telephone numbers, so you should keep this copy for future reference. If you decide not to participate in this study, the decision will not be held against you and will not affect your educational evaluations or opportunities in any way.

You are being asked to participate in this research study because you are a student at the University of Western Ontario between 18 and 30 years of age and are a native English speaker with normal hearing ability. The purpose of this study is to investigate the effect of background noise on speech intelligibility in individuals with Parkinson's disease and control subjects. In addition, we plan to obtain a detailed evaluation of the phonetic features responsible for the participants' intelligibility deficits.

This study will involve 80 participants. Twenty of the participants will have Parkinson's disease. Parkinson's disease is a neurodegenerative disease that is associated with movement deficits and speech impairment. Another group of twenty participants, who do not have a neurological condition will serve as age-matched controls. In addition, a third group of 40 participants, with no neurological condition will serve as listeners. You are being asked to serve as a listener in this study.

As a listener in this study, you will be required to listen to speech recordings from some of the participants with Parkinson's disease and some of the control participants. The speech recordings will include short sentences and conversations obtained in different levels of background noise. For some of the recordings, you will be asked to write the words that you hear on a piece of paper. For other recordings you will be asked to circle a word from a list of several multiple choices. Your written responses and multiple choice answers will be used to evaluate the participants' intelligibility and specific speech errors. For this study you will do the following four listening tasks:

<u>Listening task 1.</u> For this listening task you will listen to audio recordings of 210 sentences and attempt to identify the target word in each sentence by circling one answer from a list of four multiple choices. This will take approximately 28 minutes (8 seconds per sentence).

<u>Listening task 2.</u> For this listening task you will listen to 63 sentences and attempt to identify the target word by circling one answer from 21 possible choices. This will take about 8 minutes.

<u>Listening task 3.</u> For this listening task you will listen to 33 sentences and attempt to write each word that you hear in each sentence. This will take about 11 minutes (20 seconds per sentence).

<u>Listening task 4.</u> For this listening task you will listen to 30 sentences taken from the participants' conversations. You will attempt to write each word that you hear in each of the 30 sentences. This will take about 10 minutes.

Before completing these 4 listening tasks, we will conduct a brief hearing assessment. During this standard hearing assessment, you will hear a variety of sounds at different intensities and frequencies. This hearing assessment will take about 5 minutes. The total time for the four listening tasks and the hearing assessment will be about one hour and 15 minutes.

If you agree to participate in this study, you will be asked to make one visit to the Speech Movement Disorders Laboratory in Elborn College at the University of Western Ontario. The experimental procedures will require very little physical effort, and there is no known discomfort or risk involved in performing them. You will be seated in a comfortable chair throughout the procedures.

The procedures that will be used during this study are experimental in nature and will not provide any direct benefit to the participants, however, it is anticipated that results from this study may provide important information about the nature of the intelligibility deficits in individuals with Parkinson's disease. Financial compensation will not be provided upon completion of this study. Free parking will be provided while you are visiting the lab at Elborn College.

Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions, or withdraw from the study at any time.

All of the information obtained in this study will be held in strict confidence. Your name and any identifying information will be removed from the data. If the results of the study are published, your name will not be used and no information that discloses your identity will be released or published.

Throughout the study, all confidential information will be preserved in a locked filing cabinet in the Principal Investigator's laboratory at Elborn College, University of Western Ontario. All study materials will be destroyed after 25 years.

If requested, you will be provided with a copy of any publication related to the results of this study when it becomes available.

If you have any questions or would like additional information about this study, please contact Professor Scott Adams at the School of Communication Sciences and Disorders, Elborn College, University of Western Ontario, London, Ontario, N6G 1H1 [redacted]

If you have any questions about the conduct of this study or your rights as a research subject you may contact Dr. David Hill, Scientific Director, Lawson Health Research Institute, at [redacted]

If you agree to participate in this study, please sign the consent form on the next page.

Sincerely,

Scott Adams, Ph.D.
Professor

Appendix E. Listener Consent Form

CONSENT FORM

STUDY TITLE
Speech Intelligibility and Background Noise in Parkinson's Disease

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Talia Leszcz
MSc. Candidate,
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University of Western Ontario

I have read the Letter of Information (have had the nature of the study explained to me), and I agree to participate. All questions have been answered to my satisfaction.

Signature of Research Subject	Printed Name	Date
Signature of Person Obtaining Consent	Printed Name	Date

Appendix F. 3-way Intelligibility ANOVA

General Linear Model

Within-Subjects Factors

Measure:MEASURE_1

test	noise	Dependent Variable
1	1	DFDnn
	2	DFD65
2	1	PITnn
	2	PIT65
3	1	SITnn
	2	SIT65
4	1	ConvoNN
	2	Convo65

Between-Subjects Factors

		Value Label	N
group	1.00	Control	10
	2.00	PD	10

Descriptive Statistics

	group	Mean	Std. Deviation	N
DFDnn	Control	91.4240	8.34306	10
	PD	87.1440	9.53945	10
	Total	89.2840	8.99433	20
DFD65	Control	69.9850	19.31462	10
	PD	48.0840	22.26317	10
	Total	59.0345	23.18870	20
PITnn	Control	94.2830	4.09541	10
	PD	89.6820	7.52078	10
	Total	91.9825	6.34887	20
PIT65	Control	80.6680	11.17300	10
	PD	69.2850	23.25245	10
	Total	74.9765	18.69066	20
SITnn	Control	99.7270	.43957	10
	PD	93.5450	10.21716	10
	Total	96.6360	7.71989	20
SIT65	Control	89.7260	9.28014	10
	PD	59.4550	34.59901	10
	Total	74.5905	29.13723	20
ConvoNN	Control	97.0780	2.86338	10
	PD	93.0720	9.94497	10
	Total	95.0750	7.41319	20
Convo65	Control	85.4460	21.74140	10
	PD	58.0650	35.14508	10
	Total	71.7555	31.72197	20

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
test	Sphericity Assumed	3131.229	3	1043.743	4.809	.005	.211
	Greenhouse-Geisser	3131.229	2.487	1258.879	4.809	.008	.211
	Huynh-Feldt	3131.229	3.000	1043.743	4.809	.005	.211
	Lower-bound	3131.229	1.000	3131.229	4.809	.042	.211
test * group	Sphericity Assumed	574.057	3	191.352	.882	.456	.047
	Greenhouse-Geisser	574.057	2.487	230.794	.882	.441	.047
	Huynh-Feldt	574.057	3.000	191.352	.882	.456	.047
	Lower-bound	574.057	1.000	574.057	.882	.360	.047
Error(test)	Sphericity Assumed	11720.402	54	217.044			
	Greenhouse-Geisser	11720.402	44.772	261.782			
	Huynh-Feldt	11720.402	54.000	217.044			
	Lower-bound	11720.402	18.000	651.133			
noise	Sphericity Assumed	21446.393	1	21446.393	41.877	.000	.699
	Greenhouse-Geisser	21446.393	1.000	21446.393	41.877	.000	.699
	Huynh-Feldt	21446.393	1.000	21446.393	41.877	.000	.699
	Lower-bound	21446.393	1.000	21446.393	41.877	.000	.699
noise * group	Sphericity Assumed	3228.041	1	3228.041	6.303	.022	.259
	Greenhouse-Geisser	3228.041	1.000	3228.041	6.303	.022	.259
	Huynh-Feldt	3228.041	1.000	3228.041	6.303	.022	.259
	Lower-bound	3228.041	1.000	3228.041	6.303	.022	.259
Error(noise)	Sphericity Assumed	9218.263	18	512.126			
	Greenhouse-Geisser	9218.263	18.000	512.126			
	Huynh-Feldt	9218.263	18.000	512.126			
	Lower-bound	9218.263	18.000	512.126			
test * noise	Sphericity Assumed	894.002	3	298.001	2.919	.042	.140
	Greenhouse-Geisser	894.002	2.510	356.178	2.919	.053	.140
	Huynh-Feldt	894.002	3.000	298.001	2.919	.042	.140
	Lower-bound	894.002	1.000	894.002	2.919	.105	.140
test * noise * group	Sphericity Assumed	479.873	3	159.958	1.567	.208	.080
	Greenhouse-Geisser	479.873	2.510	191.185	1.567	.216	.080
	Huynh-Feldt	479.873	3.000	159.958	1.567	.208	.080
	Lower-bound	479.873	1.000	479.873	1.567	.227	.080
Error(test*noise)	Sphericity Assumed	5513.462	54	102.101			
	Greenhouse-Geisser	5513.462	45.180	122.034			
	Huynh-Feldt	5513.462	54.000	102.101			
	Lower-bound	5513.462	18.000	306.303			

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1067114.922	1	1067114.922	1050.416	.000	.983
group	7563.188	1	7563.188	7.445	.014	.293
Error	18286.161	18	1015.898			

Appendix G. 2-way ANOVA Intelligibility Measure

DFD General Linear Model

Within-Subjects Factors

Measure:MEASURE_1

noise	Dependent Variable
1	DFDnn
2	DFD65

Between-Subjects Factors

		Value Label	N
group	1.00	Control	10
	2.00	PD	10

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
noise	Sphericity Assumed	9150.323	1	9150.323	62.674	.000	.777
	Greenhouse-Geisser	9150.323	1.000	9150.323	62.674	.000	.777
	Huynh-Feldt	9150.323	1.000	9150.323	62.674	.000	.777
	Lower-bound	9150.323	1.000	9150.323	62.674	.000	.777
noise * group	Sphericity Assumed	776.249	1	776.249	5.317	.033	.228
	Greenhouse-Geisser	776.249	1.000	776.249	5.317	.033	.228
	Huynh-Feldt	776.249	1.000	776.249	5.317	.033	.228
	Lower-bound	776.249	1.000	776.249	5.317	.033	.228
Error(noise)	Sphericity Assumed	2627.995	18	146.000			
	Greenhouse-Geisser	2627.995	18.000	146.000			
	Huynh-Feldt	2627.995	18.000	146.000			
	Lower-bound	2627.995	18.000	146.000			

Descriptive Statistics

	group	Mean	Std. Deviation	N
DFDnn	Control	91.4240	8.34306	10
	PD	87.1440	9.53945	10
	Total	89.2840	8.99433	20
DFD65	Control	69.9850	19.31462	10
	PD	48.0840	22.26317	10
	Total	59.0345	23.18870	20

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	219983.774	1	219983.774	596.719	.000	.971
group	1713.612	1	1713.612	4.648	.045	.205
Error	6635.804	18	368.656			

PIT General Linear Model

Within-Subjects Factors

Measure:MEASURE_1

noise	Dependent Variable
1	PITnn
2	PIT65

Between-Subjects Factors

		Value Label	N
group	1.00	Control	10
	2.00	PD	10

Descriptive Statistics

	group	Mean	Std. Deviation	N
PITnn	Control	94.2830	4.09541	10
	PD	89.6820	7.52078	10
	Total	91.9825	6.34887	20
PIT65	Control	80.6680	11.17300	10
	PD	69.2850	23.25245	10
	Total	74.9765	18.69066	20

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
noise	Sphericity Assumed	2892.040	1	2892.040	27.148	.000	.601
	Greenhouse-Geisser	2892.040	1.000	2892.040	27.148	.000	.601
	Huynh-Feldt	2892.040	1.000	2892.040	27.148	.000	.601
	Lower-bound	2892.040	1.000	2892.040	27.148	.000	.601
noise * group	Sphericity Assumed	114.989	1	114.989	1.079	.313	.057
	Greenhouse-Geisser	114.989	1.000	114.989	1.079	.313	.057
	Huynh-Feldt	114.989	1.000	114.989	1.079	.313	.057
	Lower-bound	114.989	1.000	114.989	1.079	.313	.057
Error(noise)	Sphericity Assumed	1917.545	18	106.530			
	Greenhouse-Geisser	1917.545	18.000	106.530			
	Huynh-Feldt	1917.545	18.000	106.530			
	Lower-bound	1917.545	18.000	106.530			

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	278753.077	1	278753.077	1060.329	.000	.983
group	638.721	1	638.721	2.430	.136	.119
Error	4732.076	18	262.893			

SIT General Linear Model

Within-Subjects Factors

Measure:MEASURE_1

noise	Dependent Variable
1	SITnn
2	SIT65
3	SIT75

Between-Subjects Factors

		Value Label	N
group	1.00	Control	10
	2.00	PD	10

Descriptive Statistics

	group	Mean	Std. Deviation	N
SITnn	Control	99.7270	.43957	10
	PD	93.5450	10.21716	10
	Total	96.6360	7.71989	20
SIT65	Control	89.7260	9.28014	10
	PD	59.4550	34.59901	10
	Total	74.5905	29.13723	20
SIT75	Control	63.4550	28.05982	10
	PD	19.9990	25.50092	10
	Total	41.7270	34.32122	20

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
noise	Sphericity Assumed	30540.080	2	15270.040	57.263	.000	.761
	Greenhouse-Geisser	30540.080	1.874	16297.878	57.263	.000	.761
	Huynh-Feldt	30540.080	2.000	15270.040	57.263	.000	.761
	Lower-bound	30540.080	1.000	30540.080	57.263	.000	.761
noise * group	Sphericity Assumed	3572.459	2	1786.229	6.698	.003	.271
	Greenhouse-Geisser	3572.459	1.874	1906.462	6.698	.004	.271
	Huynh-Feldt	3572.459	2.000	1786.229	6.698	.003	.271
	Lower-bound	3572.459	1.000	3572.459	6.698	.019	.271
Error(noise)	Sphericity Assumed	9599.864	36	266.663			
	Greenhouse-Geisser	9599.864	33.730	284.612			

	Huynh-Feldt	9599.864	36.000	266.663			
	Lower-bound	9599.864	18.000	533.326			

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	302327.954	1	302327.954	343.790	.000	.950
group	10642.414	1	10642.414	12.102	.003	.402
Error	15829.153	18	879.397			

CONVO General Linear Model

Within-Subjects Factors

Measure:MEASURE_1

noise	Dependent Variable
1	ConvoNN
2	Convo65
3	Convo75

Between-Subjects Factors

		Value Label	N
group	1.00	Control	10
	2.00	PD	9

Descriptive Statistics

	group	Mean	Std. Deviation	N
ConvoNN	Control	97.0780	2.86338	10
	PD	92.7533	10.49394	9
	Total	95.0295	7.61346	19
Convo65	Control	85.4460	21.74140	10
	PD	64.5167	30.35299	9
	Total	75.5321	27.58778	19
Convo75	Control	68.0320	22.34923	10
	PD	31.6333	35.94121	9
	Total	50.7905	34.24197	19

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
noise	Sphericity Assumed	19340.905	2	9670.453	36.243	.000	.681
	Greenhouse-Geisser	19340.905	1.696	11404.012	36.243	.000	.681
	Huynh-Feldt	19340.905	1.975	9793.496	36.243	.000	.681
	Lower-bound	19340.905	1.000	19340.905	36.243	.000	.681

noise * group	Sphericity Assumed	2437.511	2	1218.755	4.568	.017	.212
	Greenhouse-Geisser	2437.511	1.696	1437.234	4.568	.024	.212
	Huynh-Feldt	2437.511	1.975	1234.262	4.568	.018	.212
	Lower-bound	2437.511	1.000	2437.511	4.568	.047	.212
Error(noise)	Sphericity Assumed	9071.922	34	266.821			
	Greenhouse-Geisser	9071.922	28.832	314.653			
	Huynh-Feldt	9071.922	33.573	270.216			
	Lower-bound	9071.922	17.000	533.642			

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	304933.430	1	304933.430	282.699	.000	.943
group	6001.660	1	6001.660	5.564	.031	.247
Error	18337.036	17	1078.649			

Appendix H. DFD Errors (65 dB)

Consonant sound	PD 65	CTRL 65
til	9	6
shil	8	4
dil	7	3
hil	7	2
nil	7	4
kil	6	2
lil	6	4
mil	6	7
pil	6	2
ril	6	1
vil	6	5
bil	5	4
chil	4	1
fil	4	2
thil	4	1
wil	4	2
yil	4	3
zil	3	4
gil	2	2
jil	2	3
sil	2	3

Appendix I. PIT phonetic contrasts

		Phonetic contrast	Phonetic contrast and word pair example from Kent et al. (1989)
Most Frequent errors	1	Glott - null	Glottal – null (syllable initial [h] vs. no consonant) *(hand – and)*
	2	Cons - null F	Final – consonant null *(rake – ray)*
	3	Stop - place	Stop and nasal place of articulation *(cake – take)*
	4	Clust - sing I	Initial cluster – singleton *(steak – take)*
	5	r - l	*(rock – lock)*
	6	Stop - fric	Stop – fricative *(tip – sip)*
	7	Voice final	Voiced – voiceless consonants (syllable final) *(bad – bat)*
Least Frequent Error	8	Stop - nasal	Stop and nasal place of articulation *(cake – take)*
	9	Alv - pal fricative	Alveolar – palatal fricatives *(see – she)*
	10	Clust – sing F	Final cluster – singleton *(sink – sing)*
	11	r - w	*(rock – walk)*
	12	Voice intitial	Voiced – voiceless consonants (syllable initial) *(bat – pat)*
	13	h – l vowel	High – low vowel *(feet – fat)*
	14	f – b vowel	Front – back vowel *(feed – food)*
	15	Fric – affricate	Fricative – affricate *(ship – chip)*
	16	Cons – null I	Intial – consonant null *(fair – air)*
	17	Other fricative	Other fricative places of articulation *(sigh – thigh)*
	18	Stop – Affric	Stop – Affricate *(top – chop)*
	19	l – s vowel	Long – short vowel *(beat – bit)*

Appendix J. PIT T-Test

Group Statistics

	participant_noise	N	Mean	Std. Deviation	Std. Error Mean
f_b_vowel	CT 65	10	97.2730	4.39089	1.38852
	PD 65	10	93.6370	9.62949	3.04511
h_low_vowel	CT 65	10	99.1670	2.63418	.83300
	PD 65	10	93.3340	10.97067	3.46923
l_s_vowel	CT 65	10	98.1820	3.83268	1.21200
	PD 65	10	95.4550	4.79085	1.51500
voice_initial	CT 65	10	95.5560	7.76818	2.45651
	PD 65	10	93.3340	10.73328	3.39416
voice_final	CT 65	10	91.8190	7.95916	2.51691
	PD 65	10	89.0920	15.33072	4.84800
alv_pa_fric	CT 65	10	97.5000	5.27046	1.66667
	PD 65	10	90.0000	15.36591	4.85913
other_fric	CT 65	10	95.2960	4.63821	1.46673
	PD 65	10	94.7070	5.84959	1.84980
stop_place	CT 65	10	92.0000	7.88811	2.49444
	PD 65	10	85.0000	9.71825	3.07318
fric_aff	CT 65	10	91.0000	7.37865	2.33333
	PD 65	10	94.0000	6.99206	2.21108
stop_fric	CT 65	10	94.7630	4.73561	1.49753
	PD 65	10	89.0480	10.05213	3.17876
stop_aff	CT 65	10	100.0000	.00000	.00000
	PD 65	10	95.0000	10.54093	3.33333
stop_nasal	CT 65	10	91.8190	7.95916	2.51691
	PD 65	10	89.0920	11.17409	3.53356
glott_null	CT 65	10	78.1830	22.35071	7.06791
	PD 65	10	76.3650	19.73167	6.23970
cons_null_I	CT 65	10	96.6650	3.51540	1.11167
	PD 65	10	94.0000	7.33603	2.31986
cons_null_F	CT 65	10	92.5000	10.54093	3.33333
	PD 65	10	81.2500	19.76424	6.25000
clust_sing_I	CT 65	10	94.1670	6.86137	2.16976
	PD 65	10	85.0010	12.29960	3.88948
clust_sing_F	CT 65	10	95.4550	6.42760	2.03259
	PD 65	10	90.9100	11.33722	3.58514
r_l	CT 65	10	99.0000	3.16228	1.00000
	PD 65	10	89.0000	16.63330	5.25991
r_w	CT 65	10	91.2500	8.43686	2.66797
	PD 65	10	92.5000	6.45497	2.04124

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed) *	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
f_b_vowel	Equal variances assumed	4.697	.044	1.086	18	.292	3.63600	3.34674	-3.39525	10.66725
	Equal variances not assumed			1.086	12.587	.298	3.63600	3.34674	-3.61836	10.89036
h_low_vowel	Equal variances assumed	7.867	.012	1.635	18	.119	5.83300	3.56783	-1.66274	13.32874
	Equal variances not assumed			1.635	10.034	.133	5.83300	3.56783	-2.11295	13.77895
l_s_vowel	Equal variances assumed	5.063	.037	1.406	18	.177	2.72700	1.94015	-1.34910	6.80310
	Equal variances not assumed			1.406	17.173	.178	2.72700	1.94015	-1.36322	6.81722
voice_initial	Equal variances assumed	.514	.482	.530	18	.602	2.22200	4.18984	-6.58053	11.02453
	Equal variances not assumed			.530	16.399	.603	2.22200	4.18984	-6.64256	11.08656
voice_final	Equal variances assumed	2.582	.125	.499	18	.624	2.72700	5.46241	-8.74910	14.20310
	Equal variances not assumed			.499	13.523	.626	2.72700	5.46241	-9.02759	14.48159
alv_pa_fric	Equal variances assumed	7.432	.014	1.460	18	.162	7.50000	5.13701	-3.29246	18.29246
	Equal variances not assumed			1.460	11.089	.172	7.50000	5.13701	-3.79546	18.79546
other_fric	Equal variances assumed	.111	.743	.249	18	.806	.58900	2.36073	-4.37072	5.54872
	Equal variances not assumed			.249	17.111	.806	.58900	2.36073	-4.38926	5.56726
stop_place	Equal variances assumed	.639	.434	1.769	18	.094	7.00000	3.95811	-1.31569	15.31569
	Equal variances not assumed			1.769	17.269	.095	7.00000	3.95811	-1.34098	15.34098
fric_aff	Equal variances assumed	.116	.737	-.933	18	.363	-3.00000	3.21455	-9.75352	3.75352
	Equal variances not assumed			-.933	17.948	.363	-3.00000	3.21455	-9.75492	3.75492
stop_fric	Equal variances assumed	7.470	.014	1.626	18	.121	5.71500	3.51385	-1.66732	13.09732
	Equal variances not assumed			1.626	12.807	.128	5.71500	3.51385	-1.88783	13.31783
stop_aff	Equal variances assumed	16.000	.001	1.500	18	.151	5.00000	3.33333	-2.00307	12.00307
	Equal variances not assumed			1.500	9.000	.168	5.00000	3.33333	-2.54052	12.54052
stop_nasal	Equal variances assumed	2.048	.170	.629	18	.538	2.72700	4.33830	-6.38743	11.84143
	Equal variances not assumed			.629	16.263	.538	2.72700	4.33830	-6.45772	11.91172
glott_null	Equal variances assumed	.000	1.000	.193	18	.849	1.81800	9.42811	-17.98973	21.62573
	Equal variances not assumed			.193	17.727	.849	1.81800	9.42811	-18.01158	21.64758
cons_null_I	Equal variances assumed	5.140	.036	1.036	18	.314	2.66500	2.57246	-2.73953	8.06953
	Equal variances not assumed			1.036	12.926	.319	2.66500	2.57246	-2.89568	8.22568
cons_null_F	Equal variances assumed	2.226	.153	1.588	18	.130	11.25000	7.08333	-3.63153	26.13153
	Equal variances not assumed			1.588	13.737	.135	11.25000	7.08333	-3.96960	26.46960
clust_sing_I	Equal variances assumed	2.596	.125	2.058	18	.054	9.16600	4.45375	-.19098	18.52298
	Equal variances not assumed			2.058	14.107	.059	9.16600	4.45375	-.37954	18.71154
clust_sing_F	Equal variances assumed	2.939	.104	1.103	18	.285	4.54500	4.12125	-4.11342	13.20342
	Equal variances not assumed			1.103	14.244	.288	4.54500	4.12125	-4.28001	13.37001
r_l	Equal variances assumed	7.191	.015	1.868	18	.078	10.00000	5.35413	-1.24860	21.24860
	Equal variances not assumed			1.868	9.650	.092	10.00000	5.35413	-1.98869	21.98869
r_w	Equal variances assumed	.543	.471	-.372	18	.714	-1.25000	3.35927	-8.30757	5.80757
	Equal variances not assumed			-.372	16.848	.714	-1.25000	3.35927	-8.34234	5.84234

* Note: All comparisons were evaluated using a one-tailed t-test (i.e. one tailed value p= p for 2 tailed divided by 2)

Appendix K. Mean PIT errors - three most severe participants

	Phonetic contrast	Participant 21	Participant 23	Participant 29
1	Glott - null	45.45	36.36	54.55
2	Cons - null F	37.50	25.00	62.50
3	Stop - place	30.00	20.00	20.00
4	Clust - sing I	25.00	8.33	41.67
5	r - l	10.00	10.00	50.00
6	Stop - fric	19.05	0.00	19.05
7	Voice final	45.45	0.00	27.27
8	Stop - nasal	9.09	18.18	27.27
9	Alv - pal fricative	37.50	12.50	37.50
10	Clust – sing F	27.27	27.27	0.00
11	r - w	12.50	0.00	0.00
12	Voice intitial	33.33	11.11	11.11
13	h – l vowel	0.00	8.33	33.33
14	f – b vowel	9.09	27.27	18.18
15	Fric – affricate	10.00	0.00	20.00
16	Cons – null I	20.00	6.67	13.33
17	Other fricative	17.65	5.88	0.00
18	Stop – Affric	0.00	0.00	25.00
19	l – s vowel	9.09	9.09	9.09

Appendix L . 3 Way ANOVA Speech Intensity

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

test	noise	Dependent Variable
1	1	Convo_NN
	2	Convo_65
2	1	SIT_NN
	2	SIT_65
3	1	PIT_NN
	2	PIT_65
4	1	DFD_NN
	2	DFD_65

Between-Subjects Factors

		Value Label	N
group	1.00	CONTROL	10
	2.00	PD	10

Descriptive Statistics

	group	Mean	Std. Deviation	N
Convo_NN	CONTROL	69.6976	4.32762	10
	PD	65.5389	2.62313	10
	Total	67.6183	4.08435	20
Convo_65	CONTROL	72.9850	5.39126	10
	PD	68.9418	3.36563	10
	Total	70.9634	4.84103	20
SIT_NN	CONTROL	71.0530	5.87178	10
	PD	66.8712	4.17926	10
	Total	68.9621	5.40435	20
SIT_65	CONTROL	72.2496	6.42210	10
	PD	69.3617	4.13064	10
	Total	70.8056	5.46014	20
PIT_NN	CONTROL	68.2846	4.48259	10
	PD	63.9839	3.44882	10
	Total	66.1343	4.47432	20
PIT_65	CONTROL	71.4792	4.08497	10
	PD	69.6438	2.70580	10
	Total	70.5615	3.50127	20
DFD_NN	CONTROL	66.6828	6.67960	10
	PD	64.8002	3.45728	10
	Total	65.7415	5.26583	20
DFD_65	CONTROL	72.2854	4.87871	10
	PD	70.3808	3.17055	10
	Total	71.3331	4.12199	20

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
test	Sphericity Assumed	60.171	3	20.057	2.030	.121	.101
	Greenhouse-Geisser	60.171	2.626	22.917	2.030	.130	.101
	Huynh-Feldt	60.171	3.000	20.057	2.030	.121	.101
	Lower-bound	60.171	1.000	60.171	2.030	.171	.101
test * group	Sphericity Assumed	26.377	3	8.792	.890	.452	.047
	Greenhouse-Geisser	26.377	2.626	10.046	.890	.442	.047
	Huynh-Feldt	26.377	3.000	8.792	.890	.452	.047
	Lower-bound	26.377	1.000	26.377	.890	.358	.047
Error(test)	Sphericity Assumed	533.581	54	9.881			
	Greenhouse-Geisser	533.581	47.261	11.290			
	Huynh-Feldt	533.581	54.000	9.881			
	Lower-bound	533.581	18.000	29.643			
noise	Sphericity Assumed	578.174	1	578.174	93.895	.000	.839
	Greenhouse-Geisser	578.174	1.000	578.174	93.895	.000	.839
	Huynh-Feldt	578.174	1.000	578.174	93.895	.000	.839
	Lower-bound	578.174	1.000	578.174	93.895	.000	.839
noise * group	Sphericity Assumed	9.277	1	9.277	1.507	.235	.077
	Greenhouse-Geisser	9.277	1.000	9.277	1.507	.235	.077
	Huynh-Feldt	9.277	1.000	9.277	1.507	.235	.077
	Lower-bound	9.277	1.000	9.277	1.507	.235	.077
Error(noise)	Sphericity Assumed	110.837	18	6.158			
	Greenhouse-Geisser	110.837	18.000	6.158			
	Huynh-Feldt	110.837	18.000	6.158			
	Lower-bound	110.837	18.000	6.158			
test * noise	Sphericity Assumed	76.378	3	25.459	5.223	.003	.225
	Greenhouse-Geisser	76.378	2.317	32.968	5.223	.007	.225
	Huynh-Feldt	76.378	2.827	27.018	5.223	.004	.225
	Lower-bound	76.378	1.000	76.378	5.223	.035	.225
test * noise * group	Sphericity Assumed	10.137	3	3.379	.693	.560	.037
	Greenhouse-Geisser	10.137	2.317	4.376	.693	.526	.037
	Huynh-Feldt	10.137	2.827	3.586	.693	.552	.037
	Lower-bound	10.137	1.000	10.137	.693	.416	.037
Error(test*noise)	Sphericity Assumed	263.237	54	4.875			
	Greenhouse-Geisser	263.237	41.702	6.312			
	Huynh-Feldt	263.237	50.885	5.173			
	Lower-bound	263.237	18.000	14.624			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	762090.546	1	762090.546	6871.205	.000	.997
group	396.739	1	396.739	3.577	.075	.166
Error	1996.394	18	110.911			

Curriculum Vitae

Name:	Leszcz, Talia
Post-secondary Education and Degrees:	McGill University Montreal, Quebec, Canada 2004-2008 B.A.
	The University of Tel Aviv Tel Aviv, Israel 2007
	The University of Western Ontario London, Ontario, Canada 1995-1999 MSc.
Honours and Awards:	Poster presentation contest winner, HRS Research Forum (2011)
Related Work Experience	Teaching Assistant The University of Western Ontario 2010-2012
	Research Assistant The University of Western Ontario 2010-2011

Publications:

Ben-David, B. M.; van Lieshout, P. H. M. M.; **Leszcz, T**. (2011). A resource of validated affective and neutral sentences to assess identification of emotion in spoken language after a brain injury. *Brain Injury, 25*, 206-220.

Submitted Publications:

Vigod, S., Kurdyak, P., Dennis, C., **Leszcz, T**., Tayler, V., Blumberger, D. & Seitz, D. (Submitted for review May 2012). Systematic Review of Interventions to Reduce Psychiatric Re-hospitalization in Adults with Mental Illness. *British Journal of Psychiatry.*

Oral Presentations:

Leszcz, T., Adams, S., Dykstra, A. & Jog, M. *The effect of multi-talker background noise on speech intelligibility in Parkinson's disease and controls.* Oral presentation at 5th annual Health and Rehabilitation Sciences Graduate Research Forum, Faculty of Health Sciences, University of Western Ontario, London, ON.

Valenzano, T., Clark, J., **Leszcz, T**., Jog, M., & Adams, S. *Declination of speech intensity and pitch in Parkinson's disease*.

- Oral presentation at the 13th Rehabilitation Research Colloquium. (May 20th, 2011). Queen's University, Kingston, ON. [National].
- Poster presented at the 24th Annual Western Research Forum. (February 26th, 2011). University of Western Ontario, London, ON. [Institutional].
- Poster presented at the ARGC/FHS Symposium "Field of Dreams: Seeds for Tomorrow." (February 4th, 2011). University of Western Ontario, London, ON. [Institutional].
- Poster presented at the HRS Graduate Research Forum, "Stories Worth Sharing." University of Western Ontario, London, ON. [Institutional].