8-15-2023 10:00 AM

Loudness Matching in Individuals with Parkinson's Disease and Hypophonia

Catherine Johnson, *The University of Western Ontario*

Supervisor: Adams, Scott G., *The University of Western Ontario*
A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Health and Rehabilitation Sciences

Abstract

The purpose of the present study was to investigate speech loudness perception in 15 individuals with Parkinson's disease (IWPD) and hypophonia (reduced speech intensity) and 15 healthy control (HC) participants. A loudness matching procedure was used to examine conditions involving speech loudness targets presented at various levels (60 to 80 dB SPL). The loudness response conditions included manually controlled audio playback of external speech, self-vocalized speech, amplified self-speech, and speech projected to a distance of 2 meters. For most of the loudness matching conditions, the PD group did not demonstrate the predicted deficit in loudness matching. In some loudness matching conditions, the PD group had lower (more accurate) error scores than the HC group. More specifically, for most of the loudness matching conditions involving self-vocalized (imitation) responses, the PD group had significantly lower error scores than the HC group. This result is inconsistent with previous studies of speech loudness imitation in PD. In addition, the finding that a PD group had better performance than a HC group is judged to be unique in the field of speech perception and production. Factors that may have influenced these results include the ordering of experimental conditions, the facilitating effect of a preceding limb motor task, hypophonia symptom severity, and PD-related enhancement of feedback processes. Future studies are required to replicate and further examine these speech loudness matching results in IWPD and hypophonia.

Keywords: Parkinson's Disease, hypophonia, loudness perception, speech intensity

Summary For Lay Audience

Parkinson's Disease is a degenerative neurological disorder that causes movement abnormalities and speech problems. Quiet speech, also called hypophonia is one of the most common speech symptoms in Parkinson's Disease. The purpose of the present study was to investigate speech loudness perception in 15 individuals with Parkinson's disease (IWPD) and hypophonia (reduced speech intensity) and 15 healthy control (HC) participants. A loudness matching procedure was used to examine conditions involving speech loudness targets presented at various levels (60 to 80 dB SPL). The main loudness response conditions included 1) a hand-controlled audio playback of external speech sounds through a loudspeaker and 2) their own spoken speech. The amplification and projection distance of the loudness responses was adjusted during some parts of the study. For most of the loudness matching conditions, the PD group did not demonstrate the predicted deficit in loudness matching. In some loudness matching conditions, the PD group had lower (more accurate) error scores than the HC group. More specifically, for most of the loudness matching conditions involving self-spoken responses, the PD group had significantly lower loudness matching error scores than the HC group. This result is inconsistent with previous studies of speech loudness imitation in PD. In addition, the finding that a PD group had better performance than a HC group is judged to be unique in the field of speech perception and production. Factors that may have influenced these results include the ordering of experimental conditions, the facilitating effect of a preceding limb motor task, and the severity of hypophonia in the PD group. Future studies are required to replicate and further examine these unique speech loudness matching results in IWPD and hypophonia.

Acknowledgements

First and foremost, I would like to thank my supervisor Dr. Scott Adams. Thank you for your endless support in this process and sharing your passion for motor speech research with me. I have learned so much in your presence and I am so grateful to have had the opportunity to learn and grow as a researcher under your supervision. Thank you for believing in me and my abilities as a researcher as well as supporting my curiosity in neurological speech disorders.

I would also like to thank my advisory committee, Dr. Allyson Page and Dr. Julie Theurer. Your insights and expertise have helped me tremendously throughout this process and I greatly appreciate your guidance. To my study co-investigator, Dr. Mandar Jog, thank you for your help in making this study happen and sharing your extensive movement disorder knowledge with me. I always learn so much in your presence. Thank you to Dr. Vija Parsa and Dr. Aditya Murgai for taking the time to review this thesis and provide your thoughtful insight, and for your questions during the thesis examination.

Thank you to faculty, staff and students I have met along the way during this process. Special thanks to Sydney, I appreciate all the café study sessions and writing retreats. I am forever grateful for our degrees bringing us and our passion for speech science together.

Thank you to my friends Mya and Taylor- your unwavering support will never go unnoticed. I wouldn’t be where I am today without you both. Thank you for pushing me to go above and beyond in everything that I do. To Emily, thank you for always lending a listening ear, and your careful eye in reading parts of this thesis. Your passion for academia and learning will always inspire me.

To my parents, thank you for always supporting me in furthering my education and anything I set my mind to. I appreciate your endless encouragement and belief in me, and for always being there when I need it most.

Nathan, thank you for being the best support system, and believing in me. Thanks for being my rock through it all.

Lastly, thank you to the Parkinson’s community and participants of this study. Thank you for sharing your time, experiences, and conversation. I greatly appreciate the opportunity to learn from you. This would have not been possible without you and your generosity.

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

AEP: Auditory evoked potentials

AIF: Altered intensity feedback

CP: Communication partner

dB: Decibel

HC: Healthy control

HSREB: Health Sciences Research Ethics Board

IWPD: Individuals with Parkinson's Disease

LSVT: Lee Silverman Voice Treatment

ME: Magnitude Estimation

MoCA: Montreal Cognitive Assessment

MP: Magnitude production

OAE: Otoacoustic emission

PD: Parkinson's Disease

RQ: Research Question

SNR: Speech-to-noise ratio

SPL: Sound pressure level

ToM: Theory of mind

Chapter 1

1.1 Parkinson's Disease

Parkinson's Disease (PD) is a neurological disorder which results from a deficit of dopamine in the basal ganglia. This deficit results in a wide array of symptoms, several of which involve motor impairments, such as rigidity, akinesia, and rest tremor, as well as motor speech impairments (Balestrino & Schapira, 2020; Bloem et al., 2021; Duffy, 2019). It is estimated that in industrialized countries, PD has a prevalence of 1% in those 60 years and older, and 3% in the 80 years and older population (Balestrino & Schapira, 2020; Lee & Gilbert, 2016). Bloem et al. (2021) reported in 2016, the number of those affected globally was 6.1 million, and for reasons unknown, the prevalence has been quickly rising. Bruno and DeFreitas (2019) stated that in Canada, the prevalence of PD was 170 per 100,000 people in 2013-2014, and this is expected to rise by 65% by 2031 due to Canada's aging population (Bruno & DeFreitas, 2019; Gaskin et al., 2017; Grimes et al., 2012). The incidence of PD increases with age, with a peak occurring between the ages of 70 to 79 years (Pringsheim et al., 2014). However, Bloem et al. (2021) state that PD should not be thought as exclusively affecting older populations, as 25% of affected individuals are younger than 65, and 5-10% are below the age of 50 years.

PD is characterized by cellular lesions in the neuronal cell body, called Lewy bodies (Braak et al., 2003). Disease progression can vary across individuals, depending on the severity, or number of Lewy bodies present in the affected brain regions. A hallmark of PD is lesions present in the substantia nigra, but lesions can also be found elsewhere, such as subnuclei of the thalamus and amygdala (Braak et al., 2003). Braak and colleagues (2003) broke disease progression into six stages, based on number of lesions, and the areas affected. Stage one includes the medulla oblongata, and with the addition of pontine tegmentum leading to stage two. Stage three involves the midbrain, stage four the basal prosencephalon and the mesocortex, and stages four and five both involving the neocortex (Halliday & McCann, 2009; Braak et al., 2003). Disease progression and survival is quite heterogeneous across individuals with PD. Longitudinal survival studies of PD report mean duration of disease onset to death ranging from 10 to 25 years (Macleod et al., 2014). Most of these survival studies suggest that the heterogeneity of survival duration is influenced by several factors such as the age of disease onset (older onset associated with shorter survival times) and symptom profile (i.e., earlier cognitive dysfunction and gait problems associated with shorter survival times (De Pablo-Fernandez et al., (2019)).

PD does not have a cure but is often treated with pharmaceuticals to replace the reduced amount of dopamine within the nervous system. Levodopa is the most commonly prescribed drug to individuals with Parkinson's Disease (IWPD) to help with motor symptoms, and its effects on speech symptoms continues to be explored (Cushnie-Sparrow et al., 2018; Im et al., 2018).

1.2 Speech in Parkinson's Disease

IWPD often experience motor speech impairments. It is estimated that 65%-70% of IWPD exhibit lower speech intelligibility compared to healthy controls (Coates & Bakheit, 1997; Miller et al., 2007). These speech impairments may present as festinating speech, reduced prosody, poor voice quality, and hypophonia (Ho, Bradshaw et al., 1999). Darley, Aronson and Brown (1975) identified the most distinctive characteristics of speech in hypokinetic dysarthria as: monopitch, reduced stress, monoloudness, inappropriate silences, short rushes, rapid rate, and reduced loudness level. As hypokinetic dysarthria is commonly associated with PD, this can result in reduced speech intelligibility, thus causing detrimental effects on an IWPDs ability to effectively communicate.

1.3 Hypophonia and reduced speech intensity in Parkinson's Disease

A common impairment of speech in PD is hypophonia, or reduced speech intensity. Reduced speech intensity has been identified as one of the most distinctive speech impairments of PD (Darley et al., 1975). This can become a frustrating impairment for many IWPD, as they may be continually asked to repeat themselves and may withdraw from many conversations and social interactions (Dykstra et al., 2015). Hypophonia often presents early in the disease (Logemann et al., 1997) and while the prevalence of hypophonia is not truly known, Adams and Dykstra (2009) have suggested that standardized speech testing is not curated to acknowledge the complexity of speech in PD. Thus, certain abnormalities of speech such as hypophonia or rapid rate, may not be accurately identified in standardized assessments. In general, it has been shown that IWPD speak at intensity levels 2-4 decibels (dB) sound pressure level (SPL) lower than healthy control (HC) participants in laboratory-controlled settings, and approximately 7-8 dB SPL lower than HC participants when in their regular, daily environment (Gustafsson et al., 2019). The reduction of speech loudness can also be associated with uncertainty and puzzlement in IWPD because they frequently report perceiving themselves as sufficiently loud despite other listeners having difficulty hearing their speech (Fox & Ramig, 1997; Ho et al., 2000). These reduced intensity levels can significantly impact an individual's speech intelligibility and communication effectiveness (Dykstra et al., 2015).

The effect of hypophonia on an individual's communication effectiveness, can be directly connected to their quality of life. A study by Soleimani et al. (2016) found IWPDs were unable to communicate effectively with others reported reductions in social interactions and increased feelings of depression. The reduction in social experiences in some cases were attributed to the reduced effectiveness in communication due to the reduced speech intensity (Soleimani et al., 2016). A study by Dykstra et al. (2015) investigated communicative effectiveness in PD hypophonia, and found this population experienced reduced communicative effectiveness in adverse environments such as those with increased background noise, or when speaking with a communication partner (CP) at an increased distance. The effects of hypophonia on communication effectiveness can also be felt by CPs as they often rate the IWPD's communication effectiveness as being reduced (Dykstra et al., 2015).

Why this reduction in speech loudness occurs is unknown. However, several previous studies have indicated that IWPD may have a specific deficit in the perception of self-loudness of speech and that this may have a causal role in hypophonia associated with PD (Adams et al. 2006; Clark et al., 2014; Ho, Iansek et al., 1999). This highlights the importance of conducting additional studies of self-perception of loudness in IWPD and continuing to examine the potential role of impaired loudness perception in hypophonia. The topic of self-loudness perception will be addressed in more detail in a separate section (1.6.4).

1.4 Conditions that Influence Speech Intensity in PD

Comparing external conditions that affect speech intensity in healthy control (HC) participants to IWPD may provide insight into the intensity regulation processes that are impaired in hypophonia. Previous investigations into the cause of hypophonia have postulated that reduced speech intensity could be related to a sensory deficit or a sensorimotor integration deficit (McCaig et al., 2015). Several intensity-regulation conditions or factors have been considered in previous studies of hypophonia in PD.

These include the effects of varying levels of background noise, interlocuter distances, speech tasks, levels of intensity feedback, and levels of speech amplification (Adams et al., 2006; Adams et al., 2010; Andreetta et al., 2016; Junqua et al., 1999; Senthinathan et al., 2021).

1.4.1 Background noise and Speech Intensity

Background noise has a significant effect on speech intensity in HC participants (Luo et al., 2018). In the presence of noise, adjustments are made to speech intensity levels to overcome the competing noise. This adjustment in speech intensity in response to different levels of background noise is referred to as the Lombard Effect (Lane et al., 1970). An increase in speech intensity in response to increases in environmental noise is known as a positive Lombard effect. It has been shown that this is largely an automatic phenomenon. Pick et al. (1989) found that the Lombard effect can be very robust even when individuals are explicitly trained to suppress the effect. In this study, it was found that providing the participants with instruction to suppress the Lombard effect did not result in suppression, but when visual feedback on vocal intensity was shown, the Lombard effect was able to be supressed (Pick et al., 1989). A study by Therrien et al., (2012) explored the potential sensory feedback processes that could be involved in the Lombard effect, including the potential interaction between auditory and somatosensory feedback in eliciting the Lombard effect in self-vocalization. The authors connected the comparison of the outputs during vocalization with the incoming afferent signals, to attenuation of self-generated sensory feedback. Thus, regarding the Lombard effect, self-generated vocalizations are perceived as having reduced intensity, and without alternate reliable sensory information to calibrate intensity levels, participants automatically increase vocal intensity. After finding evidence to support that auditory feedback, as well as somatosensory feedback from the speech effectors were involved in adjusting speech intensity levels, the authors suggest that there could be a possible mechanism by which sensory attenuation affects somatosensory feedback from self-vocalizations (Therrien et al., 2012).

It is known that background noise can have an impact on speech intensity in healthy controls but understanding how this impacts speech intensity in IWPD is important to explore. A study by Ho, Bradshaw et al. (1999) explored this concept by systematically increasing the intensity of background noise (pink noise at 10-30 dB above threshold) while participants read aloud and conversed with the examiner. This study found that IWPD consistently talked at a quieter intensity than HC and they did not effectively increase their speech intensity when background noise was introduced. This suggested that IWPD may have lacked a Lombard effect response, while HC exhibited a positive Lombard effect. It was concluded that IWPD were unable to appropriately adjust their speech intensity to accommodate for competing background noise. Adams et al. (2006) also explored this concept by instructing HCs and IWPDs to perform various speech tasks under different multi-talker noise conditions (50, 55, 60, 65 and 70 dB SPL noise conditions). They found that as the multi-talker noise increased, speech intensity levels also increased (positive Lombard response) in both HCs and IWPDs. However, IWPDs were consistently and significantly lower in speech intensity in comparison to HCs (Adams et al., 2006). This suggests that IWPDs consistently underestimate speech intensity, across noise conditions. However, their response to the increasing background noise was indicative of a positive Lombard Effect that appeared to show a parallel function (noise level vs. speech intensity response) to that of the HC. These opposing results may be due to differing methods of stimulus delivery, as well as the stimulus that was delivered. In the study by Ho, Bradshaw et al. (1999) sound was delivered through headphones, directly to the participants ears as well as using pink noise as the background noise. The stimulus was also presented at noise levels below 50 dB SPL. The study done by Adams et al. (2006) played the noise through a speaker, used multi-talker noise, and presented the noise at levels of 50 dB SPL and higher.

For the purposes of the present study, the above discussion was focused on the effects of noise on speech intensity. However, it should be noted that background noise can have an important effect on the clarity or intelligibility of speech. This becomes particularly important when the noise intensity level approaches that of the speech intensity level.

The "speech-to-noise ratio" (SNR) as described by Adams et al. (2008) and DeBonis and Donahue (2008), refers to the ratio at which the speech signal is competing with the background noise. This ratio can be calculated by subtracting the background noise intensity from the speech signal intensity, represented in dB. When the speech signal is louder than that of the background noise, the SNR is positive, and when the background noise is louder than the signal, it is negative. When in conversation, it is the aim to keep a positive speech-to-noise ratio, or else intelligibility and consequently, communication effectiveness, may be reduced (Adams et al., 2008; DeBonis & Donohue, 2008). It should be noted that previous researchers have suggested that the Lombard effect may be influenced by the communication context and the relative importance of maintaining intelligible communication during conditions of background noise. Thus, the Lombard effect may be composed of a fairly automatic or fundamental reflex-like component as well as a component that relates to maintaining intelligible communication (Adams et al., 2006; Dykstra et al., 2012).

1.4.2 Interlocuter distance and Speech Intensity

Another factor that influences the planning and regulation of speech intensity is the distance between the talker and the listener. This is referred to as the interlocuter distance. In general, as interlocuter distance increases the speaker increases their speech intensity to compensate for the increased distance. There is a general inverse square law that has been described for the intensity of sounds (Healey et al. 1997). This law indicates that as distance from a sound doubles or halves, the intensity of the sound will decrease or increase by 6 dB, respectively. A similar inverse square law is observed in the relationship between interlocuter distance and talker speech intensity. This relationship has been found to be fairly linear, however the slope of this linear function can be influenced by various factors (i.e., room reverberation level, ambient noise level). When the effects of interlocuter distance have been assessed in PD, it was found that IWPD adjusted their speech intensity similarly to HC when there was a change in interlocuter distance (similar slope in the distance vs intensity function). However, IWPD had consistently lower speech intensity than HC across all interlocuter distances (Adams et al., 2010; Ho, Iansek et al., 1999; McCaig et al., 2015). This result suggests that IWPD did account for interlocuter distance, but their speech intensity was still below the HC level at each interlocuter distance. Thus, there appears to be an underestimation of the appropriate speech intensity across all interlocuter distances in IWPD with hypophonia.

It should be noted that all the previous studies of interlocution distance in IWPD have involved a ‘real’ participant as the listener. No previous interlocuter distance studies in PD have used an ‘imagined’ listener. One previous interlocuter intensity study of HC did involve real vs imagined listeners (Healey et al. 1997). This study found that HC participants raised their speech intensity to comparable levels when they were instructed to imagine a listener at various distances, and when a real listener was present. Future studies are required to determine if IWPD show a similar interlocuter effect for real and imagined listeners. Such studies could provide important evidence for the potential effectiveness of an imagined interlocuter treatment strategy for hypophonia in PD. Such a strategy has been proposed by Ramig et al., (1996), in which IWPD are instructed to think louder and as if their listener is positioned at an exaggerated interlocuter distance (Healey et al., 1997).

1.4.3 Speech Tasks and Speech Intensity

The type of speech task that participants are given can influence speech intensity regulation. Speech intensity can be measured in different tasks, such as isolated vowels, sentences, reading passages, or conversation. The task chosen for the participant, has been shown to influence speech intensity in both the material spoken and the communicative context. The task has also been shown to affect both production and perception. For example, when examining the Lombard effect, Junqua et al. (1999) found that in the presence of background noise, speech intensity increased more in a conversational task, in comparison to a reading task. Interestingly, speech tasks with added cognitive requirements caused HC to increase speech intensity, but this adjustment was not made in IWPD (Ho, Bradshaw et al., 1999; Winkworth et al., 1994). The nature of the loudness matching test procedures and the need for certain experimental controls may limit the ability to examine some types of speech tasks such as conversational speech and long reading passages.

1.4.4 Altered Intensity Feedback and Speech Intensity

Altered intensity feedback (AIF), as described by Senthinathan et al. (2021), is a procedure that involves providing the talker with a constant shift in the auditory feedback intensity of their own speech. AIF can involve either increases or decreases in the feedback intensity. When positive AIF is presented to HC, so that their intensity levels are altered to be louder, participants compensate by reducing their speech intensity levels. There have been few studies that have examined this paradigm in PD. A recent study by Senthinathan et al. (2021) examined the effects of six AIF conditions on the speech intensity in HC and IWPD with hypophonia. The IWPD displayed a reduced compensation response to both increased and decreased AIF compared to the HCs. These results were interpreted as providing support for the hypothesis that hypophonia in IWPDs, is causally related to an abnormal processing of auditory information for speech intensity regulation (Senthinathan et al., 2021). The results of this study also found an interaction between the abnormal response to AIF and the type of speech task used by the IWPDs. In particular, the IWPDs showed a poorer compensation response to AIF in the context of speech tasks with clear communicative goals (i.e., conversational speech vs prolonged vowels). A study by Ho, Bradshaw et al. (1999) also found that IWPDs failed to demonstrate compensation responses to positive AIF conditions during a conversational speech task. Taken together, the results of these two previous AIF studies provide support for the hypothesis that IWPD have an abnormal processing of auditory information for speech intensity regulation.

Along with AIF studies of speech intensity, there have also been altered feedback studies involving very brief (i.e., 200-500 msec) alterations or perturbations of vocal pitch, formant frequency, or intensity. These perturbations, or quick and unexpected changes to the speech signal, typically elicit a compensatory response. However, it was found that IWPD can have responses to these brief perturbations that are quite different from the response to the longer and continuous alterations in feedback that are used in

AIF procedures. For example, several perturbation studies have found that IWPD had a significantly larger compensatory response in comparison to controls (Chen et al., 2013; Huang et al., 2016; Kiran & Larson, 2001). Similarly, when investigating the response to intensity perturbations specifically, Liu et al. (2012) found that when participants were exposed to intensity perturbations, IWPDs produced a larger magnitude of compensation response than that of the controls. These results, in concert with the results of the AIF studies, suggest that there are abnormalities with the processing of auditory feedback in IWPDs. These abnormalities may play a role in the underlying mechanism in hypophonia, and the loudness perception deficit associated with this speech symptom.

1.5 Speech Intensity Amplification in PD

One of the potential treatment methods for hypophonia in PD, involves the use of a speech intensity amplifier as an assistive device. This method typically involves a headset microphone that transmits speech to a portable amplifier and loudspeaker that boosts the intensity of speech output. Andreetta et al. (2016), investigated the efficacy of selected speech amplification devices for use in PD. Seven devices for amplification of speech were compared to unamplified speech with 65 dB multi-talker noise in the background. The study found that most speech amplification devices increased intelligibility and increased the speech-to-noise ratio significantly in IWPD. Based on these results from Andreetta et al. (2016), a study by Knowles et al. (2020) chose three speech amplification devices to compare for use in hypophonia. Specifically, device performance and user preference were evaluated. Individuals with hypophonia, and their primary CP trialed the device for a week, and indicated whether they would continue to use the devices. Majority of study participants elected to continue using the devices. However, when device preference and performance was compared across the three devices, the user preference did not reflect hierarchy of amplifier performance that was based on objective speech measures (Knowles et al., 2020). This indicates that speech amplifiers are a useful tool for individuals with hypophonia, and the type of device most suitable can vary depending on an individual's communication situation or environment.

While amplification of speech is a useful tool to be used for individuals with hypophonia, how speech amplification effects a person's self-perception of speech intensity has not been examined in previous studies of IWPD. Given that many IWPD who use speech amplification devices must manually adjust the output intensity of their amplifier to a level that is judged to be appropriate to the communication context, the accuracy of self-perception of the loudness of amplified speech may be an important consideration in this population.

1.6 Sensory and Perceptual Deficits in PD

It has been shown that PD can be associated with general sensory and perceptual deficits, including visual-spatial, visual-postural, tactile, and proprioceptive deficits (Boller et al. 1984; Bronstein et al., 1990; Conte et al., 2013; Govil et al., 2013). It has been proposed that these deficits are potentially a result of the damage to the basal ganglia circuitry, and that these sensory deficits may cause/contribute to the underlying mechanisms that result in motor symptoms in PD (Govil et al., 2013). Auditory perceptual deficits are among the previously described sensory and perceptual deficits in IWPD. Loudness perception deficits are included in these auditory perceptual deficits that have been identified in PD. Whether or not this deficit is related to other sensory deficits, remains to be determined. Loudness perception will be discussed further in section 1.6.1.

Sensorimotor integration occurs when peripheral sensory pathways relay information to cortical motor pathways so that the information can be integrated by the central nervous system, thus, executing a motor program (Abbruzzese & Berardelli, 2003). Sensorimotor deficits will occur when there is abnormal processing of the sensory information. IWPDs demonstrate an overreliance on sensory information in comparison to controls during locomotion (Almeida et al., 2005; Bronstein et al., 1990). To evaluate the use of visual information for sensorimotor processing, Alemeida et al. (2005) used different light conditions (i.e., light, and various dark conditions) in a locomotion task and found that IWPD were more reliant on visual feedback than HC, and PD were still affected when proprioception was removed (a wheelchair condition). It was suggested that there may be an impairment in proprioceptive processing of body-position relating to altered basal ganglia function in PD.

Sensorimotor integration studies of IWPD have also included investigations of the vocal tract (reviewed in Abeyesekera, 2019). A study on oral-lingual-facial sensory and motor functions by Schneider et al. (1986) found that individuals with PD were more impaired in tests of sensory function and sensorimotor integration compared to controls. Specifically, they found significant impairment in jaw proprioception, tactile localization on the tongue, gums and teeth, as well as difficulty performing targeted head movements on the basis of tactile sensory information despite having adequate motor control of head movement (Schneider et al., 1986). In addition, Hammer and Barlow (2010) found reduced vocal tract somatosensory feedback in PD, and Hegland et al. (2019) also found reduced, or blunted, sensory perception of respiratory stimuli in PD.

1.6.1 *Loudness perception in PD*

While speaking, an individual perceives the loudness of their own speech/voice, and adjustments to intensity/loudness levels are made accordingly. However, the accuracy and overall functioning of this loudness judgement has been called into question in IWPD and hypophonia. Previous studies have suggested that the reduced speech intensity levels associated with hypophonia could be attributed to a deficit in loudness perception in this population (Adams et al., 2010; Clark et al., 2014; Ho et al. 2000; Kwan & Whitehill, 2011). However, a study investigating the perception of speech loudness through a magnitude estimation task found that IWPD and controls did not differ significantly in their perceptions of self-loudness of their own speech (Dromey & Adams, 2000). However, Kwan and Whitehill (2011) provided evidence that suggests a loudness perception deficit may only occur during self-generated speech. It has also been determined that IWPD have diminished intensity discrimination, and show different patterns of loudness perception, such that they overestimate the intensity of quieter speech, and underestimate the intensity of louder speech (DeKeyser et al., 2016). This finding is similar to that of Clark et al. (2014), in which the authors described the PD participants as using a more restricted range than controls, in terms of their speech loudness perception. The varying results indicate the need to further explore abnormal loudness perception, and the mechanisms behind this phenomenon in PD, particularly with those with hypophonia.

1.6.2 Basic Auditory Functions in PD

It is important to consider basic auditory functions when inquiring about the PD population, and their speech intensity regulation. A study by De Keyser et al. (2019) investigated the primary auditory functioning in IWPD, compared to HC using audiological measurements. Primary auditory functioning was targeted to identify impairments in the lowest order stage as this could have downstream effects on higher order auditory processing, and potentially perception. This study was also done in two conditions: off and on dopaminergic medication, to investigate the role of dopaminergic treatment on auditory functions. While the study did not find significant evidence for a disturbance of auditory bottom-up functioning, there was significant evidence for an increase of otoacoustic emission (OAE) amplitude in IWPD when off their regular dopaminergic medication. The authors proposed that this increase in OAE response may relate to decreased auditory inhibition when IWPD are in an off state, and a dysfunction in the olivocochlear efferent system could be present, thus, affecting outer hair cell functioning (De Keyser et al., 2019). The result of this study aligns with a previous study of auditory evoked potentials (AEP) which also suggested that auditory processing in PD is disrupted, due to evidence of abnormal AEPs in IWPD both on and off medication (Lukhanina et al., 2009). This effect on outer hair cell functioning indicates the potential auditory dysfunction in PD and should be taken into consideration when exploring loudness perception.

A review by De Groote et al. (2020) found that auditory impairments in PD were associated with three factors: the detection of auditory deviances in basic auditory features, auditory brainstem processing, and auditory gating and selective auditory attention. There were several different discrimination tasks with which IWPD had more difficulty in comparison to HC, including frequency discrimination, intensity discrimination, rhythm discrimination, and subtle duration temporal tasks (i.e., gap detection and duration discrimination). When referring to auditory processing, both peripheral and central auditory processing were suggested to be affected in PD. However, when studying auditory brainstem processing in PD specifically, abnormalities were confined to the central auditory brainstem responses, indicating peripheral auditory nerve transmission remains intact. Auditory gaiting was also explored in this study, in which it was suggested that in PD, there is disinhibition of the neural response to irrelevant auditory stimuli, and auditory gaiting in PD leads to a deficit in the filtering of irrelevant auditory information. It was concluded that the findings on gaiting demonstrate a deficit in filtering of irrelevant auditory stimuli in several stages of central auditory processing in PD (De Groote et al., 2020). If the auditory processing abilities in this population are disrupted, this could have direct implications for the perception of loudness and self-loudness.

1.6.3 Perception of loudness of external speech and non-speech stimuli

The loudness perception of external speech stimuli (also referred to as extra-phonic speech) by IWPD was examined in a study by Clark et al. (2014), during a magnitude estimation task. In this magnitude estimation task, participants were presented with an anchor stimulus (recorded sentence at 70 dB SPL) and test stimuli (recorded sentences presented at 60, 65, 70, 75 or 80 dB SPL) and were asked to make judgments on how much louder or quieter the test stimuli were in relation to the anchor stimulus using a magnitude estimation rating procedure. This magnitude estimation task explored how IWPD perceive the loudness of external speech stimuli in comparison to control participants. It was found that IWPD did not differ significantly in the average level of their loudness ratings, but there was a significant group and estimation level interaction indicating IWPD had a less steep magnitude estimation function slope in comparison to controls. It was also determined that IWPD were using a restricted loudness range in comparison to HC, so that PD participants rated lower intensity stimuli as having a higher loudness than was perceived by the HC and the IWPD rated higher intensity stimuli as having a lower loudness level than was perceived by the HC (Clark et al., 2014). This finding was also supported in a study by De Keyser et al. (2016) which also found IWPD used a restricted loudness estimation range. This is indicative of IWPD having a deficit in the perception of the loudness of external speech stimuli.

Loudness perception and intensity discrimination of external non-speech (or quasi-speech) stimuli was also investigated in PD in a study by Richardson and Sussman (2019). This study presented participants with a naturally produced vowel stimulus which differed in intensity by 1 dB increments. In comparison to controls, IWPD showed a significant impairment in intensity discrimination. PD participants, along with healthy age-matched adults exhibited a flatter psychosocial function of loudness as well as a more reduced range when performing a loudness rating task, when compared to young controls (Richardson & Sussman, 2019). This lack of a group difference between PD and the healthy age-matched adults aligns with a study by Abur et al. (2018) which had a similar result using pure tones. Similarly, Dromey and Adams, (2000), used a warbled pure tone and did not find a group difference in perception between IWPD and age-matched controls. These differences may suggest that the perception of vowels is more like the perception of pure tones, rather than the perception of connected speech, which was used in the Clark et al. (2014) study. This warrants further investigation into potential differences in the external loudness perception of pure tones, vowels and connected speech stimuli in IWPD.

1.6.4 Perception of Self-generated speech

The above-mentioned study by Clark et al. (2014) also investigated the perception of self-generated speech, (or auto-phonic speech) in a magnitude production (MP) task. This MP task involved the following: participants read aloud an anchor sentence at their normal intensity, and this was assigned a ‘‘loudness’’ value of 100. The participants were then asked to produce sentences at loudness levels that were judged to be proportional to the numbers 25, 50, 100, 200, and 400. For example, the number 200 would reflect a loudness level that was judged to be two times louder than the ‘‘normal’’ loudness level of 100. The results of this study found that IWPD had significantly lower speech intensity than controls across all loudness conditions in the MP task. It was also noted that while PD participants were quieter across all conditions, it was unlikely this was because of a physical limitation in their ability to reach the intended intensity targets. This is because the IWPD were able to achieve levels on their highest test stimuli that were comparable to the HC levels achieved on their lower test stimuli. This finding is consistent with a study by Ho, Bradshaw et al. (1999), where across loudness conditions PD participants consistently had reduced speech intensity levels in comparison to controls, in both reading and conversational conditions. However, when explicitly cued with verbal instruction, PD participants were able to reach the intended loudness level (Ho, Bradshaw et al., 1999). These results suggest that IWPD have the capacity to reach the target intensity levels, but there is a deficit in making the appropriate loudness adjustments, unless specific attention is being put towards this task. Clark et al. (2014) also found that PD participants made significantly smaller adjustments to their intensity levels in comparison to controls. When they were instructed to speak 2 times louder or softer, their adjustments were consistently smaller than the control participant’s adjustments. This reduced perceptual range may contribute to the failure to maintain an appropriate speech intensity level in most conditions.

In an additional MP study of self-loudness ratings in IWPD and hypophonia, Abeyesekera (2019) found that IWPDs gave significantly higher self-loudness ratings compared to the self-loudness ratings of the control group. These higher self-loudness ratings by the IWPD occurred despite the finding that their speech intensity level was reduced relative to that of the control group. These results support the hypothesis that IWPDs and hypophonia have an inaccurate perception of their self-generated speech loudness and appear to overestimate their self-loudness.

A study by Dromey & Adams (2000), also employed a magnitude production task to investigate the role of loudness perception in IWPDs. There were no significant differences between the control and PD groups in any of their tasks. It is important to note however, that hypophonia was not an inclusion criterion in this study, and this may account for the differences between this study by Dromey & Adams (2000) and those obtained in the studies by Clark et al. (2014), Ho, Bradshaw et al. (1999), and Abeyesekera (2019).

1.6.5 Comparison of Loudness Perception of External Speech and Self-generated Speech

Based on previous studies that have found differences between self-loudness perception (autophonic) and external loudness perception (extraphonic) in HC (Lane et al., 1970) it would seem important to examine and compare these in IWPD to gain a better understanding of loudness perception in PD. The previously discussed study by Clark et al. (2014), evaluated both the perception of external speech and self-generated speech in PD participants with hypophonia, and healthy controls. This was done using a magnitude estimation task and a magnitude production task, respectively. Both tasks used a test sentence, rather than pure tones or other stimuli options. This ME task included a test sentence stimulus being played at 70 dB and being assigned a value of 100 to serve as a reference. The sentence would then be played at different intensities, quieter or louder than the reference stimulus, differing by 5 dB SPL. Participants would then have to make intensity judgements if the stimulus intensity was louder or quieter, by assigning the stimuli with numbers proportional to the change in intensity. A group effect between PD and controls was not found in the average loudness rating, however, there was a different pattern found between the two groups. The magnitude estimation task found that PD participants had a lower average slope value related to magnitude estimation ratings and the stimulus intensity levels, in comparison to the controls. It was found that PD participants were using a restricted loudness range when providing their estimates. In particular, the PD participants rated the quieter stimuli as louder, and the louder stimuli as quieter than the controls did. This is suggestive of IWPD using a restricted range of loudness estimations when evaluating external speech loudness. Regarding the MP task, this study found that IWPD had significantly lower speech intensity than controls across all of the self-loudness conditions in the MP task.

When the results for the MP and ME tasks are compared, the ME task had a smaller effect size than that of the MP task for the group comparisons. Thus, it appears that the IWPD in this study may have demonstrated a greater loudness perception deficit in self-loudness perception than in external loudness perception. Unfortunately, the results for the MP and ME tasks were not compared statistically in the Clark et al. (2014) study. This would appear to be a potentially important consideration in future studies.

Dromey and Adams (2000) also investigated the ME vs. MP task, however, no group differences were found for either task. As previously mentioned, hypophonia was not an inclusion criterion within this study, and this could account for the difference seen in the results of these two studies.

The above discussion highlights the need for additional studies that compare MP and ME tasks in IWPD and hypophonia. These studies could help to determine if there are impairments in autophonic and extraphonic loudness perception, the relative strength of these impairments and their potential for dissociation. The combined evaluation of autophonic and extraphonic loudness perception may also reveal causal interactions between these areas of loudness perception in IWPD and hypophonia.

Identification of specific deficits in these areas of loudness perception could play an important role in the development of new directions for the treatment of hypophonia in PD.

1.6.6 Loudness perception and the imitation of speech intensity

An alternative to the rating scale procedures for examining self-loudness perception is the imitation of intensity procedure. An imitation task is one in which study participants are presented with an external speech stimulus at a specific target intensity and then they are asked to imitate the speech intensity with their own speech. This type of speech intensity imitation task was explored in a study by Adams et al. (2006), and it was found that IWPD were consistently 3-4 dB lower than that of the controls across all target intensity conditions (60, 70 and 80 dB). These results suggest that while IWPD consistently underestimate speech intensity and do not reach intended imitation targets, even though they have the vocal capacity to reach said targets.

The speech intensity imitation task was also used in another study of IWPD and hypophonia by Clark et al. (2014). The results of this study found that IWPD had significantly and consistently lower speech intensity than controls across all the intensity imitation levels. It was noted that, while the IWPD had the capacity to reach the intended targets, their response was reduced for each of the intensity imitation targets. These results appear to support the hypothesis that IWPD have a deficit loudness perception. However, it is not clear if this deficit reflects a deficit in external loudness perception, self-loudness perception or a combination of both. Future studies of loudness imitation should consider the inclusion of an external loudness matching task. This addition may be used evaluate the role of external and self-loudness perception in loudness imitation studies of IWPD.

1.6.7 Effort and loudness perception

In previous sections, some of the literature reviewed provides support for the hypothesis that hypophonia is caused by a loudness perception deficit in PD. An alternate, or supplemental, hypothesis involving a deficit in the perception and production of effort has also been proposed (Soloman & Robin, 2005). The effort deficit hypothesis proposes that IWPD do not accurately perceive or judge the amount of effort that is required to produce an intended level of speech loudness, and that this results in reduced intensity (hypophonia).

It has been suggested that IWPD may perceive effort differently than HC, and this difference in perceptual effort could influence speech intensity regulation (Soloman & Robin, 2005). Vocal effort can be described as the perceived exertion to the perceived communicative environmental condition which employs physiological effort, experience of effort, psychological effort, effort as speech production level and effort as affected by communicative environment (Hunter et al., 2020). A study by Soloman and Robin (2005), investigated self-ratings of effort in several different tasks including daily tasks, speech, handgrip, and tongue force. It was found that IWPD provided an increased rating of effort of speech, but effort levels did not differ significantly indicating that IWPD may have a falsely inflated sense of effort (Soloman & Robin, 2005). Literature suggesting that effort is the sole reason hypophonia is limited, but this deficit is a key component to the theory behind a popular treatment for hypophonia, Lee Silverman Voice Treatment (LSVT). LSVT is an intensive treatment that targets vocal amplitude through motor learning, and individuals are encouraged to recalibrate their perception of loudness to learn to recognize when they have been speaking too quietly for the conversational context (Sapir et al., 2011). Studies of the efficacy of LSVT have found that short term, this effort focused treatment can have positive results (Yuan et al., 2020). However, the long-term effects do not have as much supporting literature, and transfer can become a problem when treatments are done in quiet clinical settings, and individuals may find themselves in different conversational context in the real-world (e.g., different interlocuter distances, varying levels of background noise).

The previous literature suggests that the role of effort in hypophonia requires further investigation. This research could include alterations to effort levels that is required to reach certain loudness targets. An example of alterations to effort would include amplification of speech at various intensities, so that level of effort can be systematically altered during speech loudness experiments.

1.6.8 Loudness Perception of Projected Speech vs. Unprojected speech

The control and regulation of speech intensity during most social communicative contexts involves the projection of one's speech to a listener at a given interlocuter distance. The appropriate projection of speech intensity involves the perception of self-loudness that incorporates the perception and judgment of projection distance (as well as other factors such as room reverberation, visibility, etc.). An impairment in the perception of projection distance (or a general impairment in distance judgement) could result in an impairment in the speech intensity of projected speech. In the case of hypophonia, it could be hypothesized that reduced speech intensity may be related to an underestimation of the interlocuter projection distance.

The extent to which an individual needs to project their speech to effectively communicate with their CP could have an impact on their loudness perception. There are several factors which could affect the judgement of projection of speech, and perception of projected vs. unprojected speech could impact the communication effectiveness for an individual. These effects should also be considered in how they impact controls and IWPD and hypophonia respectively.

1.6.8.1 Distance judgement in PD. While it has been shown that IWPD adjust speech intensity based on interlocuter distance, it was highlighted in a previous section (1.4.2) that IWPDs typically produce speech intensity that is lower than controls at most interlocuter distances. Thus, IWPD appear to underestimate the speech intensity normally produced at various interlocuter distances. An important consideration regarding this abnormality in interlocuter speech intensity relates to the IWPDs ability to effectively judge distances generally and interlocuter distance specifically. A study by Ehgoetz Martens et al. (2013) evaluated IWPD's ability to estimate distances, under static and movement conditions, and how dopaminergic medication affects these judgements. It was found that IWPD were more erroneous in the movement condition, and they underestimated target positions across all conditions in comparison to the control subjects. Medication had no effect on any of the distance judgement conditions. This study concluded that there was in increase in perceptual estimation deficits during movement and could relate to a sensory processing deficit during movement in PD (Ehgoetz Martens et al., 2013).

The projection of speech from self to an intended CP or listener involves additional factors beyond distance estimation and perception. Some of these factors relate to processes that involve being oriented to the listener's perspective. For example, during the planning of projected speech loudness the speaker may need to take into consideration not just the interlocuter distance, but also many other factors such as the listener's hearing ability, visual acuity for lip reading, language knowledge, ability to deal with background noise, cognitive ability, emotional state, familiarity with the talker, etc. Most of these listener-oriented factors have not received attention regarding their role in the regulation of speech intensity or their associated impairment in the hypophonia of PD. The following sections describe two listener-oriented concepts that may need to be considered in future studies of hypophonia, loudness perception and communicative impairment in IWPD.

1.6.8.2 Theory of mind and social perception. Theory of mind (ToM) is a concept in which individuals infer other's state of mind. It has been found that ToM is significantly impaired in IWPD (Bodden et al., 2010). The ability to infer other's state of mind could have implications for loudness perception judgements. Further research on ToM and perception in PD should be considered.

1.6.8.3 Listener-Oriented Phonetic Reduction. Phonetic reduction is a natural linguistic process in which certain sounds or segments of an utterance are reduced in duration, prominence or are entirely deleted entirely based on certain contextual factors. An example of this is when predictable words in a certain context are isolated, they become less intelligible, in comparison to when presented with the preceding contextual factors (Lieberman, 1963; Turnbull, 2019). Turnbull (2019), relates this phenomenon to ToM, so that the talker must use skills attributed to ToM such as reducing and enhancing aspects of their speech, to effectively communicate with the CP. The process of speech production includes a process of planning, and following a listener-oriented account, knowledge of the interlocuter intervenes at some point of this planning process (Turnbull, 2019). Deficits in listener-oriented processes, individually or associated with ToM deficits, could have an effect, and play a role in hypophonia. Further studies into this perspective should be considered.

Future studies could examine the association between listener-oriented factors (i.e., ToM deficits), intensity regulation and the severity of hypophonia in PD. In addition, experimental procedures could be developed to experimentally manipulate listener-oriented variables during loudness perception and production tasks. As previously mentioned, one potentially, important experimental manipulation would be to compare loudness perception during projected speech and unprojected speech. An unprojected speech loudness perception condition would reduce (or remove) the listener-oriented factors from the speech intensity task. This novel procedure will be examined in the present study and discussed in more detail in the methods section.

1.6.8.4 Communication Accommodation Theory. The communication accommodation theory is one that describes how individuals change aspects of their speech according to their perception, and meta-perception of their CP (Dragojevic et al., 2016). This theory explains the impact our perception of others has on different characteristics of our speech, such as accent, dialect, or loudness. Dragojevic and colleagues describe adjustment strategies that are used in communication settings as follows: convergence, divergence, and maintenance. Convergence includes a speaker changing their speech to be more like the other persons, while divergence refers to when a speaker alters their speech to become less similar. Maintenance is a speaker's habitual speech, in which there is no adjustment made relative to other speakers (Dragojevic et al., 2016). This theory could have implications on the reduced loudness levels as seen in PD speech, in which the speech loudness levels are not being adjusted appropriately, and this population does not accommodate their speech as a healthy control would.

1.6.9 Loudness perception of amplified vs unamplified self-speech

As previously discussed, a treatment method for IWPD and hypophonia may include using an amplification device. While this does improve speech intelligibility and help individuals effectively communicate, it has yet to be determined what amplification does to the individual's self-loudness perception. In addition, speech amplification may have implications for the role of effort in loudness perception such that loudness targets would be easier to attain, by reducing the amount of effort required. If an individual produces speech loudness targets more accurately during an amplified speech condition compared to during an unamplified speech condition, this may suggest that effort reduction may have had a positive impact on the ability of IWPD to match speech intensity targets. There have been no previous studies that have investigated the impact of speech amplification on self-loudness perception or the ability to match speech intensity in IWPDs or HCs. The current study intends to explore the effects of amplification, and its connection to the effort deficit hypothesis.

1.7 Measurement of Loudness Perception

Methods to measure loudness perception have long been discussed in the literature. Marks and Florentine (2011) indicate that the two of the main measurement methods are equal loudness matching methods and loudness scaling methods. Equal loudness matching involves having listeners determine when the loudness level of one sound (target) matches that of another (response) sound. Equal loudness matching procedures can be further broken down into different types of measurement methods, such as adjustment paradigms and adaptive models. In adjustment methods, listeners are presented with two sounds, one of which is fixed, or the target stimulus, and the second sound is of different intensity. Listeners are required to adjust the second sound to a point in which they perceive it as being the same intensity as the fixed target stimulus. These can be affected by systematic errors such as time-order bias, or comfortable listening level bias, and listeners often overestimate the fixed stimulus. Adaptive models involve the listener being presented with 2 sounds and identifying if the second sound is quieter or louder than the fixed target sound. Memory effects of the initial stimulus can influence the results of these tasks, so that listeners mistakenly make judgments according to a previous fixed target stimulus, rather than the current target. One must balance the number of trials with the variability of response, as too many trials can cause fatigue and consequently, erroneous judgements.

Equal loudness matching procedures have rarely been used to examine loudness perception in IWPD and hypophonia. Previous loudness matching studies in PD appear to be limited to an adjustment type of loudness matching study by Ho, Bradshaw et al. (1999), and the three imitation studies by Adams et al. (2006), Clark et al. (2014), and De Keyser et al. (2016).

As previously mentioned, the loudness scaling or rating method is the other major method used to measure loudness perception. The loudness scaling method has been used in several studies of loudness perception in IWPD. The previously discussed studies by Clark et al. (2014) and Dromey & Adams (2000), investigated loudness perception in

IWPD using magnitude estimation, and magnitude production loudness scaling procedures. In addition, a study by Abeyesekera (2019) used the magnitude production procedure to examine self-loudness perception in IWPD.

Finally, the previously discussed studies by Richardson and Sussman (2019) (vowels), Abur et al. (2018) (tones), and De Keyser et al. (2016) (sentences) used the magnitude estimation scaling procedure to examine external nonspeech and speech loudness perception in IWPDs.

In the current study, the loudness matching method will be used to investigate external speech loudness perception and self-loudness perception of speech in IWPD and hypophonia. For the purposes of the present study, the imitation of speech loudness procedure will be considered a type of loudness matching task applied to the measurement of self-loudness perception. The adjustment method of loudness matching will be used throughout the present study. During the loudness matching tasks examining external speech stimuli, the participants will adjust a manual volume control to match their response loudness to the target loudness. During the loudness matching tasks examining self-loudness perception, the participants will adjust the loudness of their own speech so that it matches the loudness of the target stimulus.

1.8 Rationale

The findings of the previous studies suggest that there is a deficit in the perception of speech loudness in IWPD. The precise nature of this loudness perception deficit is not completely understood. Speech loudness perception is a complex phenomenon that involves the influence and integration of many factors. Several of these factors have received limited or no attention in previous studies of loudness perception in IWPD and hypophonia. The primary aim of the present study is to determine if the speech loudness perception deficits associated with IWPD and hypophonia are influenced by the following factors: 1) the loudness perception of externally generated speech vs self-generated speech, 2) the loudness perception of projected speech vs unprojected speech, and 3) the loudness perception of amplified vs unamplified self-speech. While there are a variety of methods of investigating speech loudness perception, the loudness matching paradigm was judged to be well suited to the evaluation of the loudness perception factors that are the focus of the present study. The loudness matching paradigm was also judged to be useful for making across condition statistical comparisons (e.g., the loudness matching of external speech versus the loudness matching of self-vocalized speech). In addition, the loudness matching paradigm has received limited attention in previous studies of loudness perception in PD, and thus should be further explored.

An inquiry into the loudness perception of externally generated speech vs. self-generated speech has been deemed to be of importance. It has been discussed that there are apparent gaps in the literature concerning this topic and understanding these effects in PD would provide important insights into hypophonia and PD. Comparing the perception of externally vs. self-generated speech will provide insight to the mechanistic deficits that underlie hypophonia, such that it could be identified if said deficit is associated with external, self- generated speech, or both types of speech loudness perception. The matching procedure will involve matching external speech stimuli to the fixed target stimulus, as well as self-generated speech, and comparing the performance of these two tasks will provide important insight into the perception deficit associated with hypophonia.

The loudness perception of projected vs. unprojected speech investigation will help to inform whether there is a deficit involving distance judgements, and the ability to effectively adjust intensity levels with varying interlocuter distances. The matching procedure will include a near speaker and far speaker, to investigate how projecting speech effects the accuracy of intensity judgements.

Investigating the loudness perception of amplified vs. unamplified speech will provide information related to the effort deficit hypothesis in PD and hypophonia. Providing amplification theoretically removes, or reduces, the need for extensive effort to reach target intensity levels, and therefore would provide insight to how much an effect effort has on intensity regulation in PD. The matching procedure would provide these insights by creating a comparison between unamplified vs. amplified intensity levels, and how accurate participants are in matching target intensities under both conditions respectively.

1.9 Objectives

The purpose of the current study was to investigate speech loudness perception in individuals with Parkinson's disease (IWPD) and hypophonia. Speech loudness perception was examined using loudness matching procedures. These procedures involved matching the playback loudness of pre-recorded speech, self-vocalized speech, and amplified self-vocalized speech. In addition, speech perception was examined in loudness matching procedures that involved projected speech (i.e. response from self-location to a distant target location) and unprojected speech (i.e., target and response at same location). Overall, the current study aimed to identify if IWPDs loudness perception deficits are influenced by; external vs. self-generated speech, projected vs. non-projected speech, amplified vs. non-amplified speech, or any combination thereof.

1.10 Primary Research Questions

RQ1: Is there a difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that is played back through a response audio monitor (loudspeaker) that is at the same location as an audio monitor playing the target stimuli?

RQ2: Is there a difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that is played back through a response audio monitor (loudspeaker) that must be projected from a location nearby the participant to a distant (2 metre) audio monitor playing the target stimuli?

RQ3: Is there a difference between IWPD and HC participants in the loudness matching of self-vocalized speech in response to target speech stimuli presented via an audio monitor that is located 2 metres from the participant (i.e., projected vocal response)?

RQ4: Is there a difference between IWPD and HC participants in the loudness matching of amplified (+10 dB), self-vocalized speech in response to target speech stimuli presented via an audio monitor that is located 2 metres from the participant (i.e. projected, amplified, vocal response)?

RQ5: Is there a difference between IWPD and HC participants in the loudness matching of amplified (+10 dB), self-vocalized speech that is output from a response audio monitor (loudspeaker) that is at the same location as an audio monitor playing the target stimuli (i.e. unprojected, amplified, vocal response)?

RQ6: Is there a difference in the loudness matching of speech stimuli played back from a projected (near-participant) audio monitor versus an unprojected audio monitor at the same location as the target in IWPD and HC participants?

RQ7: Is there a difference in the loudness matching of speech stimuli played back via an audio monitor versus via self-vocalized speech in IWPD and HC participants?

RQ8: Is there a difference in the loudness matching of amplified (+10 dB) versus unamplified self-vocalized speech that is projected to a distant (2 metre) target location in IWPD and HC participants?

RQ9: Is there a difference in the loudness matching of amplified projected versus amplified unprojected self-vocalized speech in IWPD and HC participants?

Chapter 2

2. Methods

The study was approved by the Health Sciences Research Ethics Board at Western University (Appendix A) and the Lawson Health Research Institute (Appendix B).

2.1 Participants

Fifteen individuals with Parkinson's disease (IWPD) and hypophonia were recruited from the Movement Disorders Clinic, London Health Sciences Centre in London, Ontario. Inclusion criteria included: an age range of 55-85 years (M = 67.7, SD = 5.45), a neurologist's diagnosis of idiopathic Parkinson's disease, a Montreal Cognitive Assessment (MoCA) (Appendix C) of at least 21/30, no change in Parkinson-related medication for at least 6 months, no speech therapy in the previous 2 years, pass a hearing screening (500, 1000 and 2000Hz tones at 30 dB SPL), and use English as their primary language. IWPD with a prior history of speech, language, or neurological impairments that are unrelated to Parkinson's disease were excluded from the study. IWPD participants were scheduled so that they had taken their normally prescribed dose of PD related medication one hour prior to the experiment. Demographic information for PD participants can be found in Table 1.

Table 1

Demographic information for PD participants

Participant ID	Age	Gender	Diagnosis Date	MoCA
PD 01	73	Male	15 years	21
PD 02	66	Male	8 years	27
PD 03	61	Male	4 years	22
PD 04	73	Male	6 years	27
PD 05	59	Male	7 years	24
PD 06	68	Male	3 years	26
PD 07	60	Male	7 years	24
PD 08	66	Male	3 years	25
PD 09	69	Female	10 years	26
PD 10	63	Female	1 year	29
PD 11	66	Male	8 years	26
PD 12	70	Female	10 years	28
PD 13	72	Female	15 years	30
PD 14	78	Female	8 years	28
PD 15	72	Male	10 years	25

Fifteen healthy control (HC) participants, 55-85 years of age (M = 70, SD = 6.49), were recruited from the Canadian Center for Activity and Aging, Western University, London, Ontario. Inclusion /exclusion criteria included: a Montreal Cognitive Assessment (MoCA) of at least 24/30, pass a hearing screening (500, 1000 and 2000Hz tones at 30 dB

SPL), use of English as their primary language, and no prior history of speech, language, or neurological impairments. HC participant demographic information can be found in Table 2. All IWPD and HC participants were given a Health Sciences Research Ethics Board (HSREB) approved letter of information and consent form for their signature prior to the start of the study.

Table 2

Demographic information for HC participants

Participant ID	Age	Gender	MoCA
HC 01	75	Female	28
HC 02	81	Female	24
HC 03	69	Female	30
HC 04	68	Female	30
HC 05	61	Female	29
HC 06	70	Female	28
HC 07	62	Female	29
HC 08	79	Male	30
HC 09	72	Male	28
HC 10	65	Female	29
HC 11	69	Female	29
HC 12	65	Male	28
HC 13	81	Female	30
HC 14	64	Female	28
HC 15	69	Female	28

2.2 Speech stimuli

A pre-recorded sentence “I owe you a yoyo”, spoken by a 67-year-old healthy male was used as the target stimuli. Participant speech was recorded using a USB two channel audio interface (Focusrite Scarlet 2/2), a PC computer, an omni-directional condenser microphone (AKG SE300B with a CK92 Omni Capsule) and Praat recording software digitizing at 44.1 kHz and 16 bits per sample. The microphone was calibrated using a sound level meter (Quest 215) placed beside the microphone. Before each participant started the experiment, the sound level meter was used to adjust and set the output of the target audio monitor to the intended target intensity levels (60 to 80 dB SPL C scale). The sound level meter remained in position throughout the experiment and was monitored regularly to confirm that the calibration was maintained.

Target stimuli and response sounds were presented from two matched audio monitors (Yamaha HS-8) respectively. It should be noted that an audio monitor is similar in appearance to a typical loudspeaker used to listen to music, but an audio monitor has a very flat frequency output across the frequency range whereas most loudspeakers have a frequency response that is shaped to enhance instrumental and vocal music (i.e., boost the low frequency components). Audio monitors were selected for the response and target outputs in this loudness matching study in order to avoid the potential effects of frequency distortions from loudspeakers on loudness perception. In addition, it should be noted that the two audio monitors (Yamaha HS-8) were specifically produced and tested by the Yamaha company to be a specialized “matched pair” with the same electronic components and a nearly identical frequency response and sound quality.

2.3 Apparatus and Equipment Set-up

The participant, the recording measurement microphone (AKG SE300B with a CK92 Omni Capsule),, and the audio monitor presenting the target stimuli were positioned equal distances of 2 metres from each other in a triangular set-up (see Figures 1-5). This set-up was chosen so that the participant will be the same distance from the measuring microphone as that of the target audio monitor. This equalization of distance ensured that the intensity level projected from the target audio monitor was the same intensity level as the participant's speech, so that the microphone recorded and measured equivalent intensity levels.

For some of the experimental conditions the participant used a large, manually controlled volume knob (Mackie Big Knob Passive Studio Monitor Controller) to adjust the loudness level that was projected from the response audio monitor during two of the loudness matching conditions. During some of the loudness matching conditions, the participant's amplified speech intensity served as the loudness response. For these amplified speech conditions, the participant wore a headset microphone (AKG c520) attached to a pre-amplifier (ART Pro Audio Tube Mic Preamp) and was projected through the response audio monitor (Yamaha HS-8). It should be noted that the participants wore the headset microphone (AKG c520) during all of the experimental conditions and the output from this microphone was digitized and stored as a separate audio file on the desktop computer. However, the audio data related to this headset microphone was obtained for potential comparison to previous studies and was not used in the current study.

2.4 Procedures and Experimental Conditions

Five speech intensity matching conditions were completed. In each condition, the pre-recorded target speech stimulus was randomly presented twice at 5 different target intensities (60, 65, 70, 75 and 80 dB SPL) from the target audio monitor positioned 2 metres from the participant. Thus, there were 10 trials that were based on 2 randomized trials at each of the 5 target intensities. It should be noted that there was an 11^{th} trial done at the beginning of each condition. This initial trial always involved the 60 dB target loudness level and was used to help the participant transition from the previous condition to the new condition. Thus, this initial trial was considered a practice trial and was not included in the data analysis for any of the experimental conditions. Therefore, there was a total of 11 target loudness levels presented for each condition, with one practice trial followed by the 10 trials that were eventually included in the final analysis. The average of the two trials per loudness level was used in the final analysis for each condition. The participant was instructed to match the target speech loudness from the target audio monitor in several different conditions, either using 1) the playback of pre-recorded speech stimuli from a response audio monitor, 2) their own (self-vocalized) live speech or 3) their own (self-vocalized) live amplified speech projected via the response audio monitor.

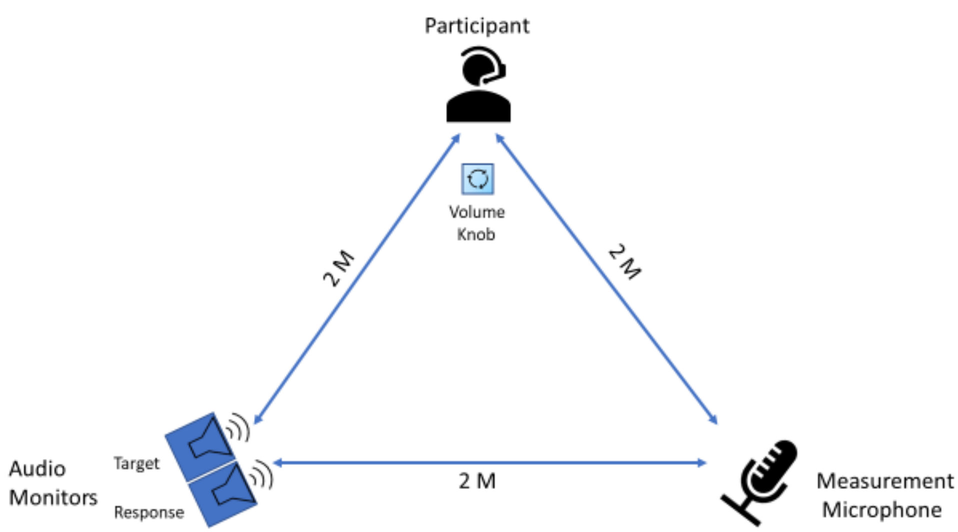
The positioning of the response audio monitor was in one of two positions during the various loudness matching conditions: 1) at 2 metres from the participant and on top of the target audio monitor, or 2) beside the participant and at 30cm from their head. There were five different loudness matching conditions. Each of the five conditions are described in the following sections.

2.4.1 Loudness Matching Condition 1: Manually Controlled Playback Response from same distance as the 2-metre target

The target speech loudness stimulus was presented from the target audio monitor and the participant’s response loudness was played back from the response audio monitor positioned at the same distance and on top of the target audio monitor, 2 metres from the participant. Because the target audio monitor and the response audio monitor were at the same location, this is considered an unprojected loudness matching condition. The participant used a manual volume control knob to adjust the playback response intensity until it was judged that the response loudness level matched the loudness of the target stimulus. For each trial, the response stimulus was played twice to allow time for the participant to adjust their response to the desired level. The equipment setup related to this first loudness matching condition is shown in Figure 1.

Figure 1

Equipment setup for the loudness matching task involving manual control of recorded speech intensity. Target and response audio monitors positioned at a similar 2 metre distance from the participant

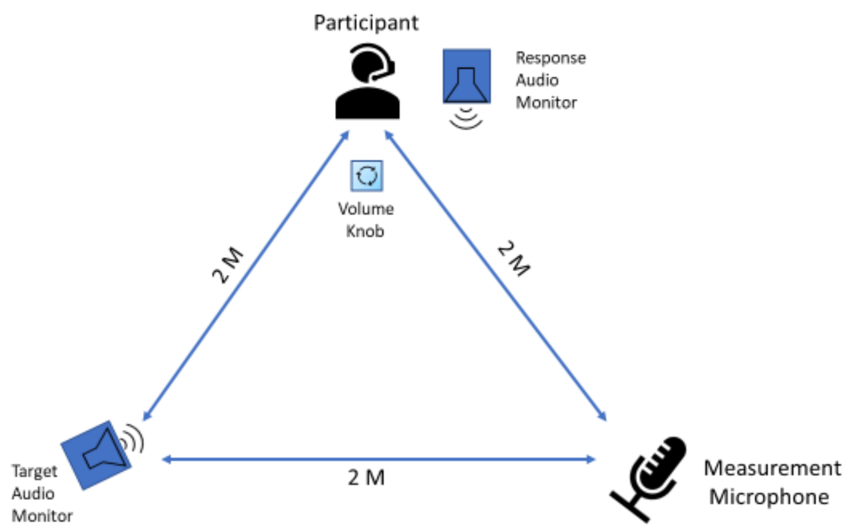


2.4.2 Loudness Matching Condition 2: Manually Controlled Playback Response from a position near the participant (and projected to the 2-metre target)

The target speech loudness stimulus was presented from the target audio monitor and the participant's response loudness was played back, using pre-recorded speech, from the response audio monitor positioned at 30cm from the participant's head. The participant used a manual volume control knob to adjust the playback response intensity until it was judged that the response loudness level matches the loudness of the target stimulus. For this condition, the participant was instructed to match the projected loudness of the response sounds to the projected loudness of the target stimulus. The equipment setup related to the second loudness matching condition is shown in Figure 2.

Figure 2

Equipment setup for the loudness matching task involving manual control of recorded speech intensity. Target audio monitor positioned at 2 metres. The response audio monitor is close to the participant and thus a projected response is required to match the target loudness

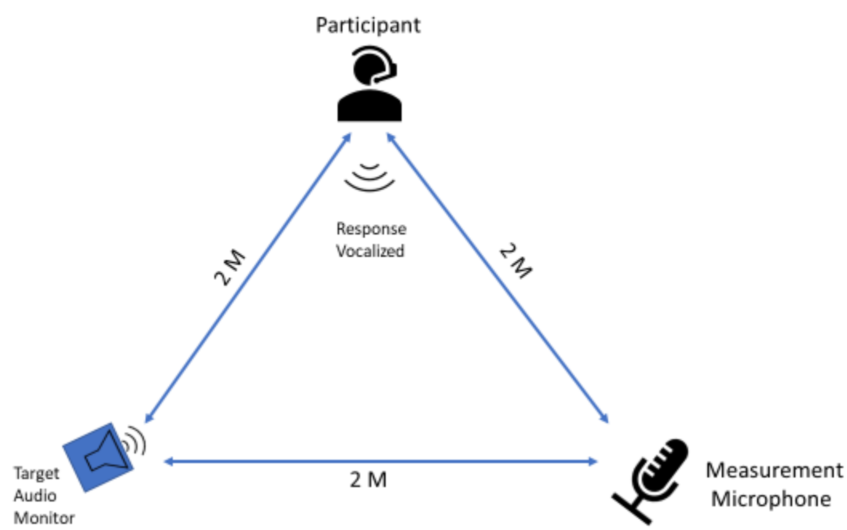


2.4.3 Speech Loudness Matching Condition 3: Unamplified, Vocalized Loudness Response by the Participant (projected to the 2-metre target)

The target speech loudness stimulus was presented from the target audio monitor located 2 metres from the participant. The participant used their unamplified, vocalized speech as the response loudness and attempted to match the projected target loudness with their own projected response loudness. For this condition, the participant was instructed to match the projected loudness of their vocalized response sounds to loudness of the distant (2-meter) target stimulus. The equipment setup related this third loudness matching condition is shown in Figure 3.

Figure 3

Equipment setup for the loudness matching task involving vocalized speech intensity as the response. The target audio monitor positioned at 2 metres presents the recorded target speech intensity. Because the participant is 2 metres from the target, this task involved a projected vocal response

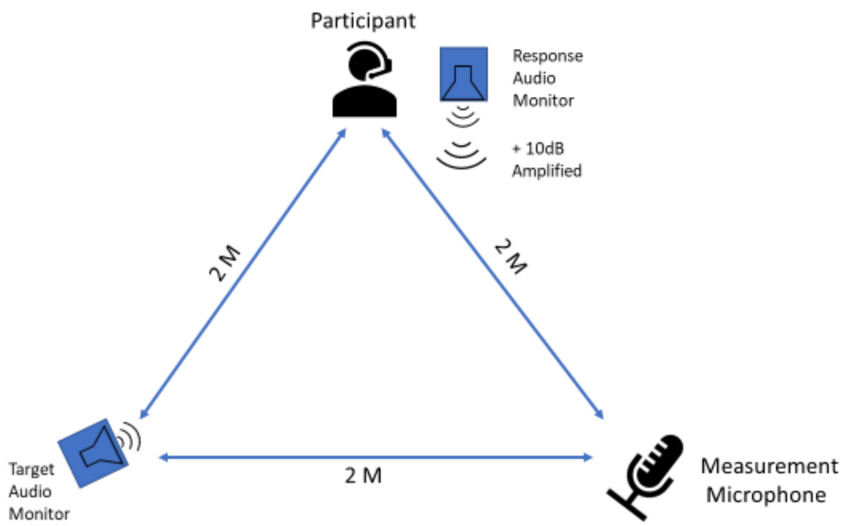


2.4.4 Speech Loudness Matching Condition 4: Amplified (+10 dB), Vocalized Loudness Response by the Participant (projected to the 2-metre target)

The target speech loudness stimulus was presented from the target audio monitor located 2 metres from the participant. The participant wore a headset microphone attached to a pre-amplifier that provided a +10 dB amplification to the participant's speech output from the response audio monitor. Using this +10 dB amplified vocalized speech as the response loudness the participant attempted to match the distant target loudness with their own projected response loudness. For this condition, the participant was instructed to match the projected loudness of their amplified vocalized response sounds to the loudness of the target stimulus. The equipment setup related this fourth loudness matching condition is shown in Figure 4.

Figure 4

Equipment setup for the loudness matching task involving amplified (+10 dB) and vocalized speech intensity as the response. The target audio monitor positioned at 2 metres presents the recorded target speech intensity. Because the response audio monitor is close to the participant, a projected response is required to match the target loudness

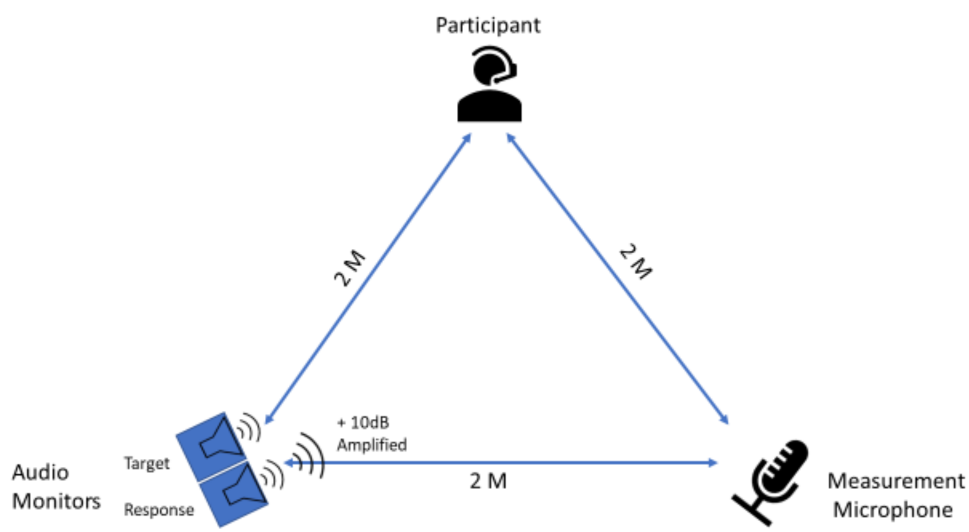


2.4.5 Speech Loudness Matching Condition 5: Amplified (+10 dB), Vocalized Loudness Response at the same 2-metre distance as the target

The target speech loudness stimulus was presented from the target audio monitor located 2 metres from the participant. The participant wore a headset microphone attached to a pre-amplifier that provided a +10 dB amplification to the participant's speech output from the response audio monitor. Using this +10 dB amplified vocalized speech as the response loudness the participant attempted to match the loudness from the target audio monitor with their amplified loudness from the response audio monitor positioned at the same 2-metre distance as the target audio monitor. For this condition, the participant was not required to project their loudness to a distance because the target and response audio monitors were at the same 2-metre location. The equipment setup related this fifth loudness matching condition is shown in Figure 5.

Figure 5

Equipment setup for the loudness matching task involving amplified (+10 dB) and vocalized speech intensity as the response. The target audio monitor positioned at 2 metres presents the recorded target speech intensity. The response audio monitor is at the same 2 metre distance from the participant for this loudness matching condition



2.5 Data Analysis

The digitized speech recordings obtained from the measurement microphone (located 2 metres from participant and audio monitors) during the experimental conditions were loaded in to Praat Software. The speech sound file was viewed in Praat's view and edit display and manual cursors and scroll functions were used to locate the target and response speech waveforms for each target level (60, 65, 70, 75, 80 dB SPL target). Cursors placed on either side of the identified waveform were used to obtain the average speech intensity value for the waveform. For each target level, a loudness matching error score was obtained by subtracting the intensity of the response speech waveform from the intensity of the target waveform. This loudness matching error score obtained for each trial was the primary dependent measure in the study.

2.6 Statistical Analysis

The data related to the first 5 primary research questions, RQ1 through RQ5, were analyzed using five, separate, 2-way repeated measures analysis of variance (RM-ANOVA) tests each with a group factor with 2 levels (IWPD and HCs) and a loudness/intensity level factor with 5 levels (60, 65, 70, 75, 80 dB SPL). The dependent measure in all statistical tests involved the loudness matching error score (target speech intensity minus response speech intensity).

The data related to research questions RQ6, RQ7, RQ8 and RQ9 were analyzed using 4 separate 3-way RM-ANOVA tests with a group factor with 2 levels (IWPD and HCs) and a loudness/intensity level factor with 5 levels (60, 65, 70, 75, 80 dB. The third factor, related to pairs of conditions, changed with each RQ as follows: RQ6 involved a projection factor (projected vs unprojected) with external speech stimuli, RQ7 involved a response mode factor (playback vs self-vocalized speech), RQ8 involved an amplification factor (amplified vs unamplified), and RQ 9 involved a projection factor (projected vs unprojected with amplified self-vocalized speech.

2.7 Power analysis

Only one previous study of speech loudness matching in PD has been reported (Ho, et al., 2000). In addition, three previous studies of speech loudness imitation in PD have been reported (Adams et al., 2006; Clark et al., 2014; De Keyser et al., 2016). Unfortunately, the study by DeKeyser et al., 2016, did not use hypophonia as an inclusion criterion for the participants with IWPD and failed to show a significant difference in speech intensity between their PD and control participants. Therefore, this study was not included in the power analysis.

The speech loudness matching study by Ho et al. (2000) involved one condition (playback perception of reading) that is comparable to Condition 1 (Manually Controlled Playback Response of a read sentence) in the present study. The conditions in both studies involve the loudness matching of previously recorded speech that was read aloud at different intensity levels. Both studies involve the use of a manually controlled knob used by participants to match the loudness of the target and response stimuli. The Ho et al. (2000) study found a difference between the PD group and the control group (n=15 per group) of 2.93 dB (PD = 65.21 dB and C = 62.28 dB). The PD group over-estimated the loudness of the stimuli relative to the control group. Unfortunately, the Ho study only provided the SD values in the form of error bars in a figure. Based on a careful visual inspection of the figure, the SD is estimated to be 2 dB for both the PD and HC results related to this loudness matching group comparison. Using this group difference value (2.93 dB) and the estimated SD value (2 dB), the effect size is estimated to be dz = 1.46 (dz = M/SD = 2.93/2). Using G*Power 3.1.9.2 software (Faul et al., 2007) and the proposed n=15 per group, p=.05, and dz=1.46, the power was estimated as .97. This power analysis is related to the planned post-hoc analysis involving the comparison of the PD and HC groups in Condition 1.

The imitation of speech loudness study by Adams et al., (2006) involved an imitation task that was comparable to condition 3 in the present study (Speech Loudness Matching using an unamplified, vocalized loudness response by the participant projected to a 2-metre target). In the Adams et al. (2006) study, PD and control participants (n=10 in each group) imitated a sentence (I owe you a yoyo) presented at target intensity levels of 60, 70 and 80 dB. The PD group had an average imitation response intensity that was approximately 2.5 dB lower than that of the control group. This difference was significant ($p = 0.013$). The estimated SD for the two groups was 2.25 dB. Using this group difference value (2.5 dB) and the estimated SD value (2.25 dB), the effect size is estimated to be dz = 1.11 (dz = M/SD = 2.5/2.25). Using G*Power 3.1.9.2 software (Faul et al., 2007) and the proposed n=15 per group, p=.05, and dz=1.11, the power was estimated as .83.

The second imitation of speech loudness study by Clark et al., (2014) involved an imitation task that was comparable to condition 3 in the present study (Speech Loudness Matching using an unamplified, vocalized loudness response by the participant projected to a 2-metre target). In the Clark et al. (2014) study, PD and control participants (PD group n=17; C group n = 25) imitated a sentence (The puppies chased the ball) presented at target intensity levels of 60, 65, 70, 75 and 80 dB. The PD group had an average imitation response intensity for the 70 and 75 dB targets that were 2.33 dB lower than that of the control group. This difference was significant ($p = 0.011$). The SD for the two groups was 2.46 dB. Using this group difference value (2.33B) and the SD value (2.46 dB), the effect size is estimated to be dz = .95 (dz = M/SD = 2.33/2.46). Using G*Power 3.1.9.2 software (Faul et al., 2007) and the proposed n=15 per group, p=.05, and dz=.95, the power was estimated as .71.

Across these 3 power analyses, it appears that an average power estimate for the present speech loudness matching study involving of 15 participants in both the PD and control groups would be .84 ((.97 + .83 + .71) / 3).

Chapter 3

3. Results

3.1 Speech Loudness Matching Condition 1 (RQ 1): Manually Controlled Playback Response from same distance as the 2-metre target

The results of the speech loudness matching in condition 1 addressed RQ1. RQ1 examined the difference between IWPD and HC participants in the loudness matching of manually controlled playback response, presented at the same 2-metre distance as the target speech stimuli presented via an audio monitor (i.e., unprojected manual control response). Matching of playback response was done to 5 target loudness levels (60, 65, 70, 75 and 80 dB). A two-way repeated measures ANOVA was used to address this research question.

The descriptive statistics and average group results related to the 5 loudness matching levels for both the PD and HC groups are shown in Table 3 and Figure 6 respectively.

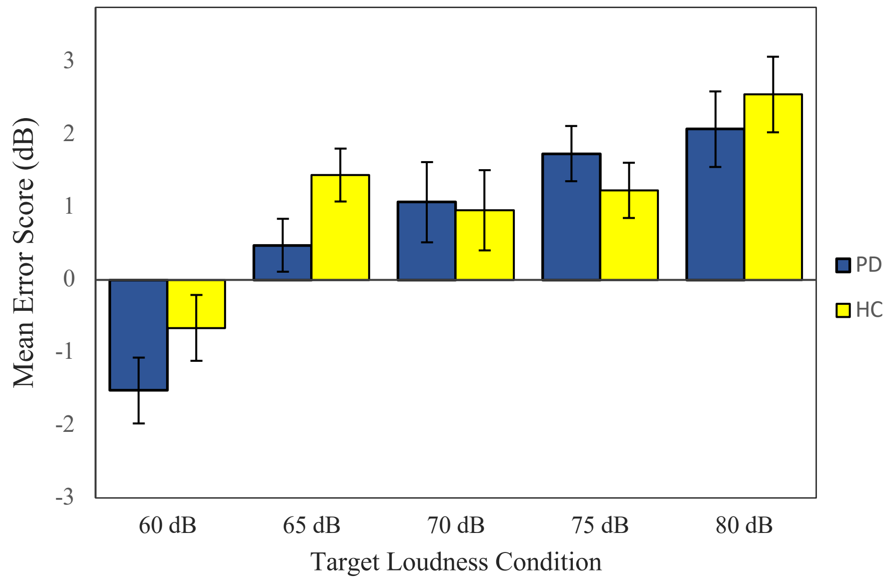
Table 3

Descriptive statistics for the error scores in condition 1

Loudness Level	PD		HC		Total	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-1.52	2.11	-0.66	1.31	-1.09	1.78
65 dB	0.48	1.53	1.44	1.28	0.96	1.47
70 dB	1.07	2.61	0.96	1.53	1.01	2.10
75 dB	1.74	1.23	1.23	1.68	1.49	1.47
80 dB	2.07	1.99	2.55	2.03	2.31	1.99

Figure 6

Mean error scores for PD and HC groups obtained for the 5 loudness matching levels during condition 1. Error bars represent one standard error above and below the mean



The results of the two-way (group by loudness level) ANOVA indicated that there was no significant main effect of group (F (1,28) = 1.25, p = 0.273, η^2 = .04) with PD participants having a similar marginal mean (M = 0.77; SE = .21) to that of the control participants (M = 1.11; SE = .213). However, there was a significant main effect of the loudness level (F (4,112) = 15.21, p = < 0.001, η^2 =.35). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 4. A significant difference was found for each of the pairwise comparisons at the 60 dB loudness level.

Table 4

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels (60, 65, 70, 75 and 80 dB) in condition 1

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values 60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-1.09	.32	-				
65 dB	0.96	.26	**<.001***	-			
70 dB	1.01	.39	**.015***	1.00	-		
75 dB	1.48	.27	**<.001***	1.00	1.00	-	
80 dB	2.31	.37	**<.001***	.138	.087	.073	-

** = significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

The group by loudness level interaction was not significant ($F(4,112) = 0.96$, $p = 0.406$, $\eta^2 = .033$). This is illustrated in Figure 6, which shows that the PD and HC participants showed a similar pattern of results across the 5 loudness levels. This non-significant interaction is further illustrated by the pairwise post-hoc comparisons presented in Table 4.

In order to illustrate this group by loudness level interaction in more detail, a post-hoc analysis related to the pairwise comparisons of group differences at each loudness level was performed. These post-hoc results are presented in Table 5.

Table 5

Post-hoc results related to the comparison of the PD versus HC group error scores at each of the 5 loudness matching levels obtained during condition 1

Loudness Level	PD		HC		HC - PD difference score t-test			
	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	F-value	*p value*
60 dB	-1.52	2.11	-0.66	1.31	0.86	0.64	1.81	**.190**
65 dB	0.48	1.53	1.44	1.28	0.96	0.51	3.52	**.071**
70 dB	1.07	2.61	0.96	1.53	-0.11	0.78	0.02	**.888**
75 dB	1.74	1.23	1.23	1.68	-0.51	0.54	0.89	**.354**
80 dB	2.07	1.99	2.55	2.03	0.48	0.73	0.42	**.521**

In summary, these results related to RQ1 indicate that there was no difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that was played back through a manually controlled response audio monitor (loudspeaker) that was at the same location as an audio monitor playing the target stimuli.

3.2 Speech Loudness Matching Condition 2 (RQ 2): Manually Controlled Playback Response from position near the participant (projected to the 2-meter target)

The results of the speech loudness matching in condition 2 addressed RQ2. RQ2 examined the difference between IWPD and HC participants in the loudness matching of manually controlled playback response, presented at a position near the participant, 2-metre distance from the target speech stimuli presented via an audio monitor (i.e., projected manual control response). Matching of playback response was done to 5 target loudness levels (60, 65, 70, 75 and 80 dB). A two-way repeated measures ANOVA was used to address this research question.

The descriptive statistics and average group results related to the 5 loudness matching levels for both the PD and HC groups are shown in Table 6 and Figure 7 respectively.

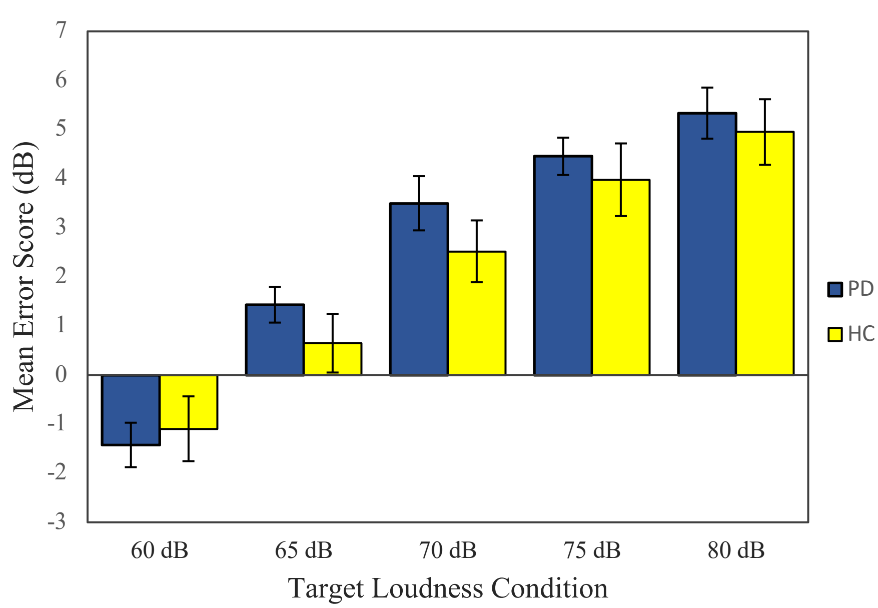
Table 6

Descriptive statistics for the error scores in condition 2

Loudness Level	PD		HC		Total	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-1.42	2.40	-1.09	2.71	-1.26	2.52
65 dB	1.43	2.40	0.65	2.23	1.04	2.31
70 dB	3.50	2.10	2.52	2.74	3.01	2.45
75 dB	4.45	2.67	3.98	3.04	4.21	2.82
80 dB	5.33	2.22	4.95	2.91	5.14	2.55

Figure 7

Mean error scores for PD and HC groups obtained for the 5 loudness matching levels during condition 2. Error bars represent one standard error above and below the mean



The results of the two-way (group by loudness level) ANOVA indicated that there was no significant main effect of group (F (1,28) = 0.311, p = 0.582, η^2 = .01) with PD participants having a similar marginal mean (M = 2.66; SE = .58) to that of the control participants (M = 2.20; SE = .58). However, there was a significant main effect of the loudness level (F (4,112) = 107.42, p = < 0.001, η^2 =.79). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 7. A significant difference was found for each of the pairwise comparisons across loudness levels.

Table 7

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels (60, 65, 70, 75 and 80 dB) in condition 2

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values				
			60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-1.09	.32	-				
65 dB	0.96	.26	**<.001***	-			
70 dB	1.01	.39	**<.001***	**<.001***	-		
75 dB	1.48	.27	**<.001***	**<.001***	**.010***	-	
80 dB	2.31	.37	**<.001***	**<.001***	**<.001***	**.011***	-

* = *significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

The group by loudness level interaction was not significant (F (4,112) = 1.02, p = 0.387, η^2 = .035). This is illustrated in Figure 7, which shows that the PD and HC participants showed a similar pattern of results across the 5 loudness levels. This non-significant interaction is further illustrated by the pairwise post-hoc comparisons presented in Table 8. None of these post-hoc comparisons were significant.

Table 8

Post-hoc results related to the comparison of the PD versus HC group error scores at each of the 5 loudness matching levels obtained during condition 2

Loudness Level	PD		HC		HC – PD difference score t-test			
	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	F-value	*p value*
60 dB	-1.42	2.40	-1.09	2.71	0.33	0.93	0.12	**.727**
65 dB	1.43	2.40	0.65	2.23	-0.78	0.85	0.85	**.363**
70 dB	3.50	2.10	2.52	2.74	-0.98	0.89	1.21	**.281**
75 dB	4.45	2.67	3.98	3.04	-0.48	1.05	0.21	**.652**
80 dB	5.33	2.22	5.33	2.91	-0.38	0.94	0.16	**.687**

In summary, these results related to RQ2 indicate that there was no difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that was played back through a manually controlled response via an audio monitor (loudspeaker) that had to be projected from a location nearby the participant to a distant (2 metre) audio monitor playing the target stimuli.

3.3 Speech Loudness Matching Condition 3 (RQ 3): Unamplified, Vocalized Loudness Response by the Participant (projected to the 2-meter target)

The results of the speech loudness matching in condition 3 addressed RQ3. RQ3 examined the difference between IWPD and HC participants in the loudness matching of self-vocalized speech in response to 5 loudness levels (60, 65, 70, 75 and 80 dB) of target speech stimuli presented via an audio monitor that was located 2 meters from the participant (i.e., projected vocal response). The statistical method used to address this research question (RQ3) was the two-way repeated measures ANOVA.

The descriptive statistics and average group results related to the 5 loudness matching levels for both the PD and HC groups are shown in Table 9 and Figure 8 respectively.

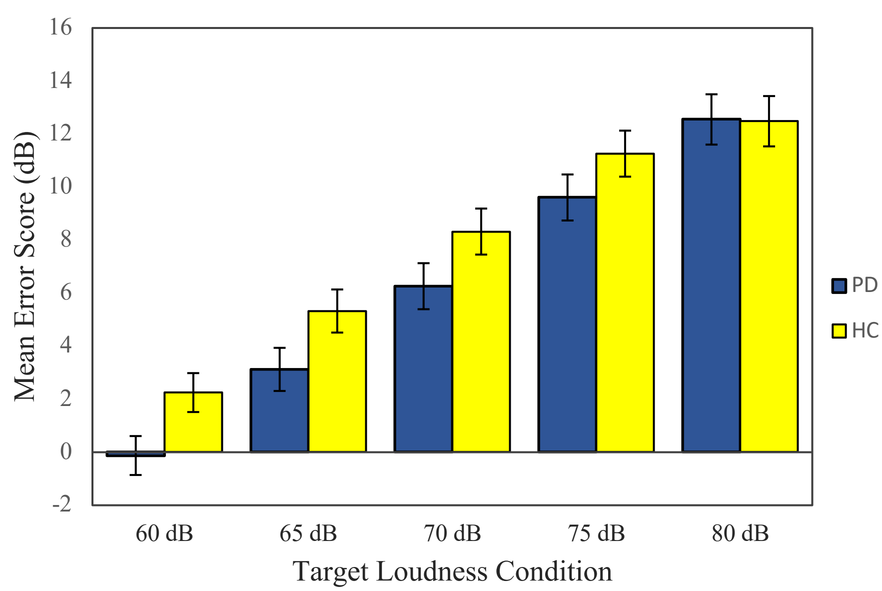
Table 9

Descriptive statistics for the error scores in condition 3

Loudness Level	PD		HC		Total	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-0.12	3.36	2.25	2.20	1.06	3.04
65 dB	3.12	3.52	5.33	2.73	4.23	3.29
70 dB	6.26	3.81	8.32	2.84	7.29	3.46
75 dB	9.61	3.45	11.26	3.27	10.43	3.41
80 dB	12.55	4.09	12.48	3.20	12.52	3.61

Figure 8

Mean error scores for PD and HC groups obtained for the 5 loudness matching levels during condition 3. Error bars represent one standard error above and below the mean



The results of the two-way (group by loudness level) ANOVA indicated that there was no significant main effect of group (F (1,28) = 2.12, p = 0.156, η^2 = .07) with PD participants having a similar marginal mean (M = 6.28; SE = .79) to that of the control participants (M = 7.92; SE = .79). In contrast, there was a significant main effect of the loudness level (F (4,112) = 408.44, p = < 0.001, η^2 =.936). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 10. In general, a significant difference was found for each of the pairwise comparisons of the loudness levels and this is reflected in the general pattern involving a gradual increase in the error score as the loudness level increased from 60 to 80 dB.

Table 10

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels (60, 65, 70, 75 and 80 dB) in condition 3

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values				
			60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	1.06	.51	-				
65 dB	4.22	.57	**<.001***	-			
70 dB	7.29	.61	**<.001***	**<.001***	-		
75 dB	10.43	.61	**<.001***	**<.001***	**<.001***	-	
80 dB	12.51	.67	**<.001***	**<.001***	**<.001***	**<.001***	-

* = *significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

It is important to note that the main effects for group and loudness level factors needs to be qualified because of the finding of a significant group by loudness level interaction (F (4,112) = 4.73, p = 0.012, η^2 = .145). This significant interaction is illustrated in Figure 8, which shows that the previously described trend involving an increase in the error score as the loudness level increases was different for the PD participants relative to the control participants. In particular, across the loudness levels, the HC participants showed a greater error score than the PD participants at the lower loudness level (60 dB) but not at the higher loudness levels (80 dB).

In order to illustrate this group by loudness level interaction in more detail, a post-hoc analysis related to the pairwise comparisons of group differences at each loudness level was performed. These post-hoc results are presented in Table 11. The post-hoc analysis found a significant group difference in the error scores for the 60 dB loudness level ($p = 0.030$) with the HC participants showing a higher error score ($M= 2.25$; $SD = 2.19$) than the PD participants ($M = -0.124$; $SD = 3.36$). For all of the other loudness levels, no significant group difference was observed (the 65 dB level approached significance with a $p = 0.066$). These post-hoc results indicate that the significant group by level interaction is related to a greater group difference in the error scores for the lower loudness level (60 dB) than for the higher loudness levels (70, 75, 80 dB).

Table 11

Post-hoc results related to the comparison of the PD versus HC group error scores at each of the 5 loudness matching levels obtained during condition 3

Loudness Level	PD		HC		HC – PD difference score t-test			
	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	F-value	*p value*
60 dB	-0.12	3.36	2.25	2.20	2.37	1.03	5.23	**.030***
65 dB	3.12	3.52	5.32	2.72	2.20	1.15	3.66	**.066**
70 dB	6.26	3.81	8.32	2.84	2.06	1.22	2.81	**.104**
75 dB	9.61	3.45	11.26	3.27	1.65	1.22	1.81	**.189**
80 dB	12.55	4.09	12.48	3.20	-.06	1.34	.003	**.960**

** = significant at $p < 0.05$ (Adjustment for multiple comparisons: Bonferroni)*

In summary, these results related to RQ3 indicate that there was a difference between the PD and HC participants at some of the loudness levels during the loudness matching of self-vocalized speech in response to target speech stimuli presented via an audio monitor that was located 2 metres from the participant (i.e., projected vocal response). More specifically, the PD participants had a lower error score than the HC participants during the lower loudness levels and this reach significance for the 60 dB loudness level.

3.4 Speech Loudness Matching Condition 4 (RQ 4): Amplified (+10 dB) Vocalized Loudness Response by participant (projected to the 2-metre target)

The results of the speech loudness matching in condition 4 addressed RQ4. RQ4 examined the difference between IWPD and HC participants in the loudness matching of amplified (+10 dB) self-vocalized speech presented via an audio monitor near the participant, in response to 5 loudness levels (60, 65, 70, 75 and 80 dB) of target speech stimuli presented via an audio monitor that was located 2 meters from the participant (i.e., projected amplified vocal response). The statistical method used to address this research question (RQ4) was the two-way repeated measures ANOVA.

The descriptive statistics and average group results related to the 5 loudness matching levels for both the PD and HC groups are shown in Table 12 and Figure 9 respectively.

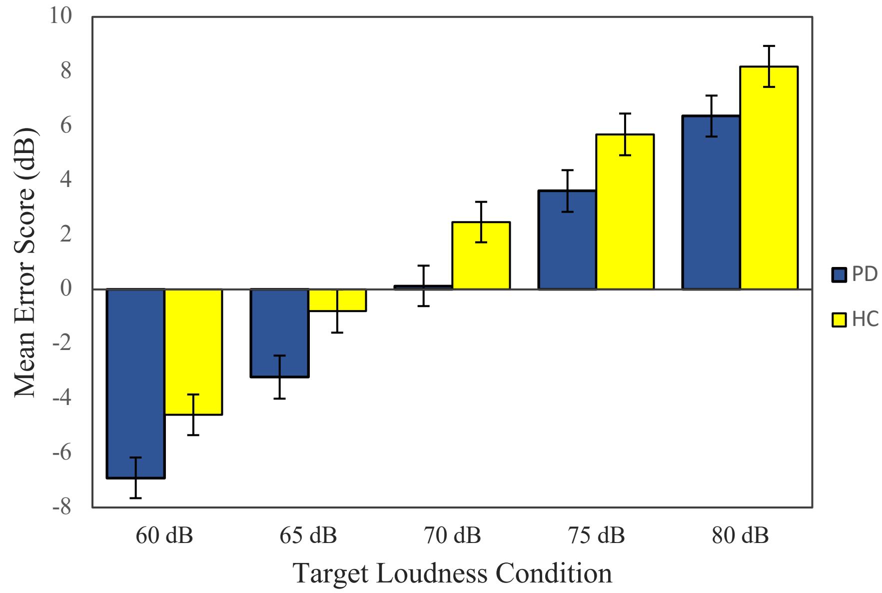
Table 12

Descriptive statistics for the error scores in condition 4

Loudness Level	PD		HC		Total	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-6.91	3.45	-4.59	2.18	-5.75	3.07
65 dB	-3.22	3.75	-0.79	2.15	-2.01	3.25
70 dB	0.13	3.51	2.47	2.04	1.30	3.06
75 dB	3.61	3.44	5.69	2.39	4.65	3.09
80 dB	6.36	3.54	8.18	2.10	7.27	3.01

Figure 9

Mean error scores for PD and HC groups obtained for the 5 loudness matching levels during condition 4. Error bars represent one standard error above and below the mean



The results of the two-way (group by loudness level) ANOVA indicated that there was a significant main effect of group (F (1,28) = 4.78, p = 0.037, η^2 = .14) with PD participants having a significantly different marginal mean (M = -.005; SE = .71) to that of the HC participants (M = 2.19; SE = .71). Additionally, there was a significant main effect of the loudness level (F (4,112) = 593.49, p = < 0.001, η^2 =.955). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 13. In general, a significant difference was found for each of the pairwise comparisons of the loudness levels and this is reflected in the general pattern involving a gradual increase in the error score as the loudness level increased from 60 to 80 dB. It should be noted that the 60 dB and 65 dB loudness levels were associated with negative error scores in both groups.

These negative error scores correspond to participant response intensity levels that were greater than the target intensity levels.

Table 13

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels (60, 65, 70, 75 and 80 dB) in condition 4

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values 60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-5.75	.53	-				
65 dB	-2.01	.56	**<.001***	-			
70 dB	1.30	.52	**<.001***	**<.001***	-		
75 dB	4.65	.54	**<.001***	**<.001***	**<.001***	-	
80 dB	7.27	.53	**<.001***	**<.001***	**<.001***	**<.001***	-

** = significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

The group by loudness level interaction was not significant (F (4,112) = 0.33, p = 0.785, η^2 = .012).

Table 14

Post-hoc results related to the comparison of the PD versus HC group error scores at each of the 5 loudness matching levels obtained during condition 4

Loudness Level	PD		HC		HC - PD difference score t-test			
	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	F-value	*p value*
60 dB	-6.91	3.45	-4.59	2.18	2.31	1.05	4.81	**.037***
65 dB	-3.22	3.75	-0.79	2.15	2.42	1.17	4.70	**.039***
70 dB	0.13	3.51	2.47	2.04	2.34	1.05	4.97	**.034***
75 dB	3.61	3.44	5.69	2.39	2.07	1.08	3.68	**.065**
80 dB	6.36	3.54	8.18	2.10	1.82	1.06	2.94	**.098**

** = significant at $p < 0.05$ (Adjustment for multiple comparisons: Bonferroni)*

In summary, these results related to RQ4 indicate that there was a difference between the PD and HC participants during the loudness matching of amplified (+10 dB), self-vocalized speech in response to target speech stimuli presented via an audio monitor that was located 2 metres from the participant (i.e. projected, amplified, self-vocalized). More specifically, the PD participants had a lower error score than the HC participants during the lower loudness levels and this reached significance for the 60 dB, 65 dB and 70 dB loudness levels. In addition, the intensity of the vocal response was greater than the target intensity (negative error score) for the 60 dB and 65 dB loudness matching levels.

3.5 Speech Loudness Matching Condition 5 (RQ 5): Amplified (+10 dB) Vocalized Loudness Response at the same 2-metre distance as the target

The results of the speech loudness matching in condition 5 addressed RQ5. RQ5 examined the difference between PD and HC participants in the loudness matching of amplified (+10 dB) self-vocalized speech presented via an audio monitor located 2 metres from the participant, in response to 5 loudness levels (60, 65, 70, 75 and 80 dB) of target speech stimuli presented via an audio monitor that was located 2 meters from the participant (i.e., unprojected amplified vocal response). The statistical method used to address this research question (RQ5) was the two-way repeated measures ANOVA.

The descriptive statistics and average group results related to the 5 loudness matching levels for both the PD and HC groups are shown in Table 15 and Figure 10 respectively.

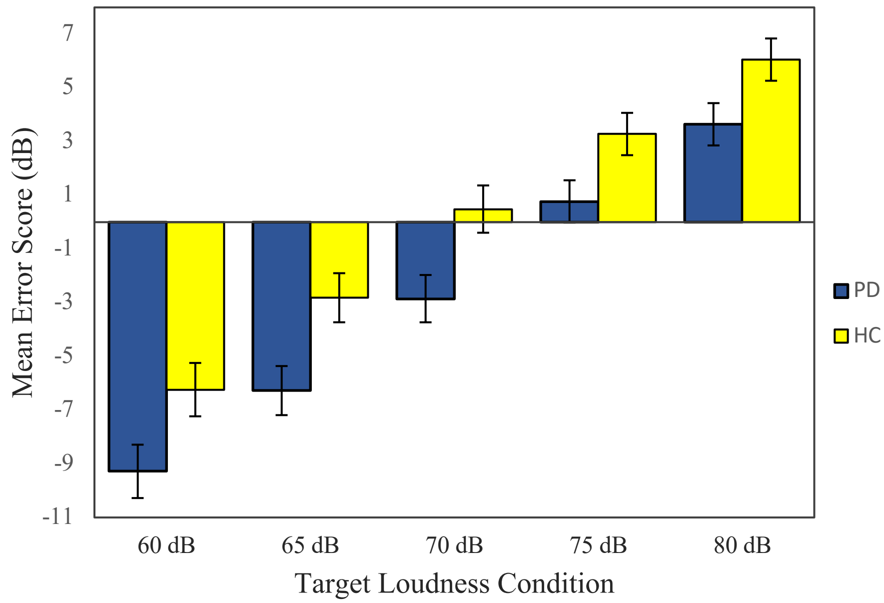
Table 15

Descriptive statistics for the error scores in condition 5

Loudness Level	PD		HC		Total	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-9.28	3.45	-6.24	4.21	-7.76	4.09
65 dB	-6.27	3.15	-2.81	3.90	-4.54	3.90
70 dB	-2.85	3.41	0.49	3.41	-1.18	3.75
75 dB	0.77	2.88	3.28	3.22	2.03	3.26
80 dB	3.65	3.07	6.05	3.03	4.85	3.24

Figure 10

Mean error scores for PD and HC groups obtained for the 5 loudness matching levels during condition 5. Error bars represent one standard error above and below the mean



The results of the two-way (group by loudness level) ANOVA indicated that there was a significant main effect of group (F (1,28) = 6.27, p = 0.018, η^2 = .18) with PD participants having a significantly different marginal mean (M = -2.79; SE = .83) to that of the HC participants (M = 0.15; SE = .83). Additionally, there was a significant main effect of the loudness level (F (4,112) = 549.92, p = < 0.001, η2 =.952). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 16. In general, a significant difference was found for each of the pairwise comparisons of the loudness levels and this is reflected in the general pattern involving a gradual increase in the error score as the loudness level increased from 60 to 80 dB.

Table 16

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels (60, 65, 70, 75 and 80 dB) in condition 5

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values				
			60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-7.76	.70	-				
65 dB	-4.54	.65	**<.001***	-			
70 dB	-1.18	.62	**<.001***	**<.001***	-		
75 dB	2.03	.56	**<.001***	**<.001***	**<.001***	-	
80 dB	4.85	.56	**<.001***	**<.001***	**<.001***	**<.001***	-

** = significant at $p < 0.05$ (Adjustment for multiple comparisons: Bonferroni)*

The group by loudness level interaction was not significant (F (4,112) = 1.23, p = 0.294, η^2 = .042).

In order to examine the group effect at each loudness level, a post-hoc analysis related to the pairwise comparisons of group differences at each loudness level was performed. These post-hoc results are presented in Table 17. The post-hoc analysis found a significant group difference in the error scores at each of the 5 loudness levels with the HC participants showing a higher error score than the PD participants at each level. It should be noted that the 60 dB and 65 dB loudness levels were associated with negative error scores in both groups. In addition, the PD participants had a negative error score during the 70 dB loudness level. These negative error scores correspond to participant response intensity levels that were greater than the target intensity levels.

Table 17

Post-hoc results related to the comparison of the PD versus HC group error scores at each of the 5 loudness matching levels obtained during condition 5

Loudness Level	PD		HC		HC - PD difference score t-test			
	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	F-value	*p value*
60 dB	-9.28	3.45	-6.24	4.21	3.04	1.41	4.69	**.039***
65 dB	-6.27	3.15	-2.81	3.90	3.46	1.29	7.15	**.012***
70 dB	-2.85	3.41	0.49	3.41	3.33	1.24	7.17	**.012***
75 dB	0.77	2.88	3.28	3.22	2.51	1.11	5.07	**.032***
80 dB	3.65	3.07	6.05	3.03	2.41	1.11	4.68	**.039***

** = significant at $p < 0.05$ (Adjustment for multiple comparisons: Bonferroni)*

In summary, these results related to RQ5 indicate that there was a difference between the PD and HC participants during the loudness matching of amplified (+10 dB), self-vocalized speech that was output from a response audio monitor that was at the same location as an audio monitor playing the target stimuli (i.e. unprojected, amplified, self-vocalized response). More specifically, the PD participants had a significantly lower error score than the HC participants during each of the five loudness levels. In addition, for both groups, the intensity of the vocal response was greater than the target intensity (negative error score) for the 60 dB and 65 dB loudness matching levels. The PD group also had a negative error score for the 70 dB loudness level.

3.6 *Summary of speech loudness matching conditions 1-5*

The following is a brief summary of the results related to RQ1 to RQ5. RQ1 and RQ2 examined loudness matching of externally presented target stimuli and responses involving manually controlled external stimuli. For these manually controlled loudness matching responses no group effect was observed and therefore the PD participants performed these loudness matching conditions similar to HC participants. RQ3, RQ4 and RQ5 examined loudness matching procedures that involved self-vocalized responses instead of the manually controlled responses used in RQ1 and RQ2. RQ3 involved unamplified self-vocalized responses while RQ4 and RQ5 used amplified self-vocalized responses. For all three of these self-vocalized RQs, group differences emerged. For RQ3, the unamplified self-vocalized responses of the PD participants had lower loudness matching error scores than HC controls during the lower loudness levels (significant for the 60 dB level), but not the higher loudness levels. This group difference became more apparent and occurred across all 5 loudness levels during the RQ4 and RQ5 conditions. For RQ4 and RQ5, the amplified self-vocalized responses of the PD participants had lower loudness matching error scores than the controls during most of the 5 loudness levels (significant for 3/5 levels for RQ4 and 5/5 levels for RQ5).

These results for RQ1 to RQ5 indicate that there were differences in the loudness matching performance of PD and HC participants that were influenced by the nature of the stimulus-response conditions. Greater group differences in the loudness matching error scores appeared to emerge as conditions shifted from external manually controlled responses, to self-vocalized responses, to amplified, self-vocalized responses. There may have been additional effects of projection distance on the loudness matching error scores of the amplified self-vocalized responses (RQ4 versus RQ5). The following sections related to RQ6 to RQ9 attempt to examine more specifically the influence of the above stimulus-response conditions on the group differences in greater detail by presenting statistical comparisons of selected pairs of conditions (i.e., RQ6 involves condition 1 versus condition 2).

3.7 Speech Loudness Matching Condition 1 versus 2 (RQ 6): Is there a difference in the loudness matching of speech stimuli played back from a projected (near-participant) audio monitor (condition 2) versus an unprojected audio monitor at the same location as the target (condition 1) in IWPD and control participants?

The following section relates to a comparison of the results obtained for speech loudness matching condition 1 versus condition 2 and addresses RQ6. Condition 1 examined loudness matching of manually controlled external speech stimuli response played back via an audio monitor at the same 2-metre distance used to play the external speech target via an audio monitor. Condition 2 examined loudness matching of manually controlled external speech stimuli response played back via an audio monitor near the participant and 2-metres away from the target audio monitor used to play the external target speech stimuli. Both conditions involved the PD and HC participants and 5 loudness levels (60, 65, 70, 75 and 80 dB) of target speech stimuli. The statistical method used to address this research question (RQ6) was the three-way repeated measures ANOVA that involved a group factor with two levels (PD vs HC), a loudness level factor with 5 levels (60, 65, 70, 75, and 80 dB), and a condition factor with 2 levels (condition 1 vs condition 2). The primary dependent (outcome) measure was the average error score which was determined by subtracting the response speech intensity (dB SPL) from the target speech intensity for each trial to obtain a per trial error score and then averaging these scores for each loudness level. Thus, RQ6 examined if there were differences in the error scores during the loudness matching of unprojected, manually controlled, external stimuli (condition 1) versus projected, manually controlled, external stimuli (condition 2). In addition, this comparison of conditions was examined and compared across the PD and

HC groups and at the 5 different loudness levels to determine if there were group by condition by level interactions.

The descriptive statistics and average group results related to the 2 conditions and the 5 loudness matching levels for both the PD and HC groups are shown in Table 18 and Figure 11.

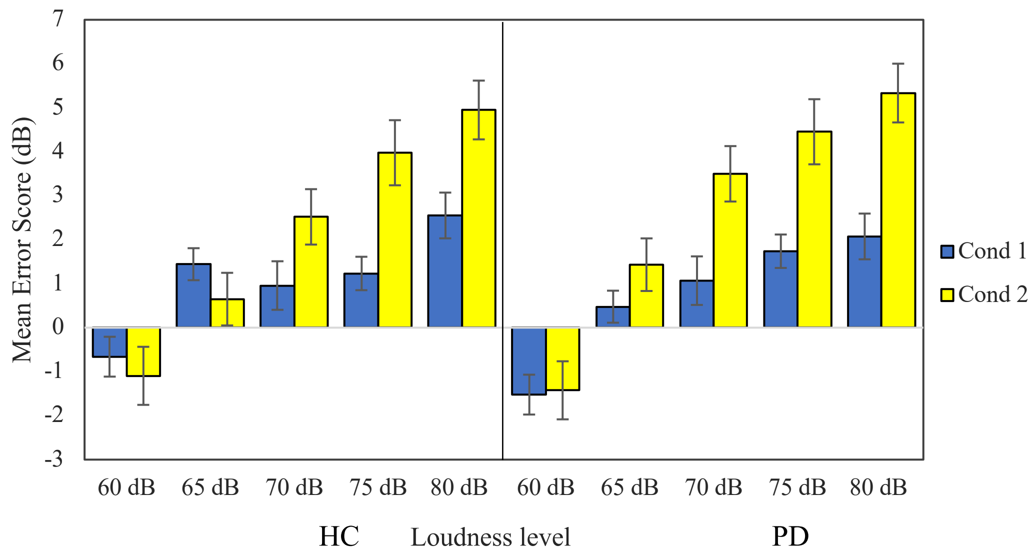
Table 18

Descriptive statistics for the error scores related to the 2 conditions (1 and 2) and the 5 loudness matching levels obtained for the PD and HC groups

Condition 1	PD		HC		Total	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-1.52	2.11	-0.66	1.31	-1.09	1.78
65 dB	0.48	1.53	1.44	1.28	0.96	1.47
70 dB	1.07	1.23	0 .96	1.52	1.01	2.10
75 dB	1.74	1.23	1.23	1.68	1.49	1.47
80 dB	2.07	2.00	2.55	2.02	2.31	1.99
Condition 2	PD		HC		Total	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-1.42	2.40	-1.09	2.71	-1.26	2.52
65 dB	1.43	2.40	0.65	2.23	1.04	2.31
70 dB	3.50	2.10	2.52	2.74	3.01	2.45
75 dB	4.45	2.67	3.98	3.04	4.21	2.82
80 dB	5.33	2.22	5.33	2.91	5.14	2.55

Figure 11

Mean error scores for the HC and PD groups obtained for the 5 loudness matching levels during condition 1 and condition 2. Error bars represent one standard error above and below the mean



The results of the three-way (condition by group by loudness level) ANOVA indicated that there was no significant main effect of group (F (1,28) = 0.017, p = 0.896, η^2 = .001) with PD participants having a similar marginal mean (M = 1.71; SE = .32) to that of the control participants (M =1.65; SE = .32). In contrast, there was a significant main effect of the loudness level (F (4,112) = 68.07, p = < 0.001, η^2 =.709). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 19. In general, a significant difference was found for each of the pairwise comparisons of the loudness levels and this is reflected in the general pattern involving a gradual increase in the error score as the loudness level increased from 60 to 80 dB.

Table 19

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels. These marginal means reflect a combination of the 2 conditions (1 and 2) and the 2 groups

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values 60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-1.175	.318	-				
65 dB	1.000	.258	**<.001***	-			
70 dB	2.011	.292	**<.001***	**.023***	-		
75 dB	2.850	.321	**<.001***	**<.001***	**.045***	-	
80 dB	3.727	.343	**<.001***	**<.001***	**<.001***	**.001***	-

** = significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

There was a significant main effect of condition (F (1,28) = 12.88, p = 0.001, η^2 =.315). This effect relates to a significantly higher error score for condition 2 (M =2.43; SE = 0.411) relative to condition 1 (M = 0.936; SE = 0.151).

It is important to note that the main effects for the group, loudness level, and condition factors need to be evaluated relative to any potential interactions. The group by loudness level interaction was not significant (F (4,112) = 1.05, p = 0.364, η^2 = .036). Additionally, the group by condition interaction was not significant (F (1,28) = 0.91, p = 0.347, η^2 = .032), and the group by loudness level by condition interaction was not significant (F (4,112) = 0.86, p = 0.469, η^2 =.030). In contrast, the condition by loudness level interaction was significant (F (4,112) = 17.25, p = < 0.001, η^2 =.381). This significant interaction is illustrated in Figure 11 which shows that the previously described trend involving an increase in the error score as the loudness level increases was different for condition 1 relative to condition 2. In particular, condition 1 shows a more gradual increase in error scores (flatter slope) as loudness level increases, while condition 2 shows a much greater increase in error scores (steeper slope) as loudness level increases.

In order to illustrate this condition by loudness level interaction in more detail, a post-hoc analysis related to the pairwise comparisons of condition differences at each loudness level was performed. These post-hoc results are presented in Table 20. The post-hoc analysis found a significant, condition 1 versus condition 2, difference in the error scores at 3 of the 5 loudness levels (70 dB, 75 dB, 80 dB) with the condition 2 error score having a greater value than condition 1 for all of the loudness levels, except for the 60 dB loudness level. The significant interaction is reflected in the finding that the mean condition 1 versus condition 2 difference (Mdiff) gradually decreased from the near zero 60 dB loudness level (Mdiff = 0.16; SE = .48) to the more negative 80 dB loudness level (Mdiff = 2.82; SE = .49).

Table 20

Post-hoc results related to the comparison of the marginal mean error scores for Condition 1 (C1) versus Condition 2 (C2) at each of the 5 loudness matching levels

	Condition 1		Condition 2		C1 – C2 difference score t-test		
Loudness Level	Mean	*SE*	Mean	*SE*	Mean difference	Standard error difference	*p value*
60 dB	-1.09	.32	-1.26	.47	0.16	.48	**.733**
65 dB	0.96	.25	1.04	.42	-0.08	.47	**.866**
70 dB	1.01	.39	3.01	.44	-1.99	.60	**.002***
75 dB	1.48	.26	4.21	.52	-2.73	.52	**<.001***
80 dB	2.31	.36	5.14	.47	-2.82	.49	**<.001***

** = significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

In summary, these results related to RQ6 indicate that there was a significant difference between condition 1 (the condition that involved loudness matching of external target stimuli and manually controlled response stimuli played back from 2 audio monitors both at a 2-meter distance from the participant (not projected)) and condition 2 (the condition that involved loudness matching of external target stimuli presented from an audio monitor at a 2-meter distance and manually controlled response stimuli played back from an audio monitor near the participant (projected)). The projected condition (condition 2) had a larger error score than the unprojected condition (condition 1) in both the PD and HC groups. There was no significant difference between the PD and HC groups for this condition 1 versus condition 2 effect.

3.8 Speech Loudness Matching Condition 2 versus 3 (RQ 7): Is there a difference between condition 2 (the condition involving loudness matching of external target stimuli presented from an audio monitor at a 2-meter distance and manually controlled response stimuli played back from an audio monitor near the participant (projected)) and condition 3 (the condition involving the loudness matching of external target stimuli presented from an audio monitor at a 2-meter distance and a self-vocalized speech response, projected to the 2-meter audio monitor target) in PD and HC groups?

The following section relates to a comparison of the results obtained for speech loudness matching condition 2 versus condition 3 and addressed RQ7. Condition 2 examined loudness matching of manually controlled external speech stimuli played back via an audio monitor, projected to the 2-metre target. Condition 3 examined loudness matching of self-vocalized speech, projected to the 2-metre target. Both conditions involved the PD and HC participants and 5 loudness levels (60, 65, 70, 75 and 80 dB) of target speech stimuli. The statistical method used to address this research question (RQ7) was the three-way repeated measures ANOVA that involved a group factor with two levels (PD vs HC), a loudness level factor with 5 levels (60, 65, 70, 75, and 80 dB), and a condition factor with 2 levels (condition 2 vs condition 3). The primary dependent (outcome) measure was the average error score which was determined by subtracting the response speech intensity (dB SPL) from the target speech intensity for each trial to obtain a per trial error score and then averaging these scores for each loudness level. Thus, RQ7 examined if there were differences in the error scores during the loudness matching of external stimuli (condition 2) versus self-produced stimuli (condition 3). In addition, this comparison of conditions was examined and compared in the PD and HC groups to determine if there were group by condition differences (an interaction).

The descriptive statistics and average group results related to the 2 conditions and the 5 loudness matching levels for both the PD and HC groups are shown in Table 21, and Figure 12.

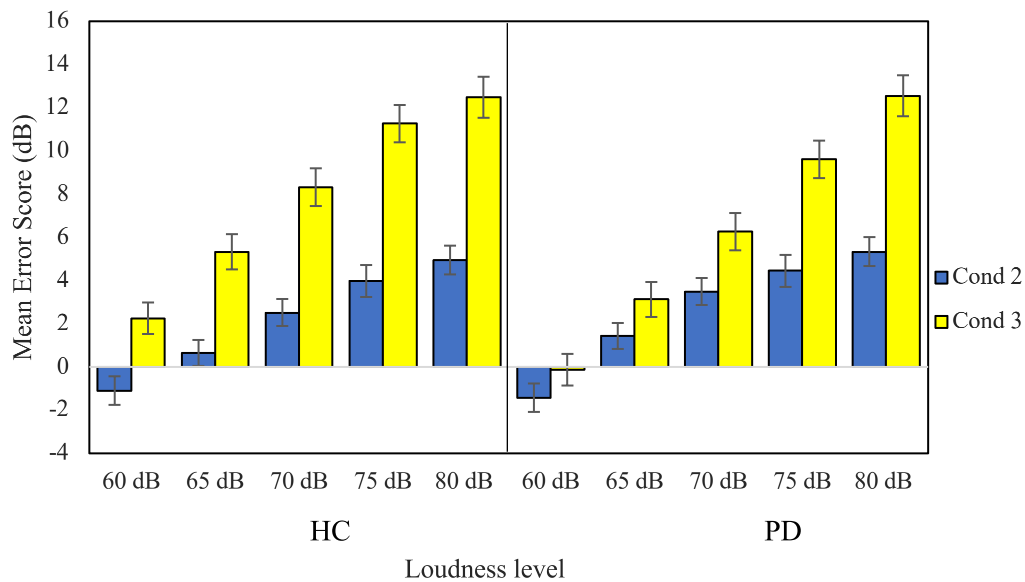
Table 21

Descriptive statistics the error scores related to the 2 conditions (2 and 3) and the 5 loudness matching levels obtained for the PD and HC groups

Condition 2	PD		HC		Total	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-1.42	2.40	-1.09	2.71	-1.26	2.52
65 dB	1.43	2.40	0.65	2.23	1.04	2.31
70 dB	3.50	2.10	2.52	2.74	3.01	2.45
75 dB	4.45	2.67	3.98	3.04	4.21	2.82
80 dB	5.33	2.22	4.95	2.91	5.14	2.55
Condition 3	**PD**		**HC**		**Total**	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-0.12	3.36	2.25	2.20	1.06	3.04
65 dB	3.12	3.52	5.33	2.73	4.23	3.29
70 dB	6.26	3.81	8.32	2.84	7.29	3.46
75 dB	9.61	3.45	11.26	3.27	10.43	3.41
80 dB	12.55	4.09	12.48	3.20	12.52	3.61

Figure 12

Mean error scores for the HC and PD groups obtained for the 5 loudness matching levels during condition 2 and condition 3. Error bars represent one standard error above and below the mean



The results of the three-way (condition by group by loudness level) ANOVA indicated that there was no significant main effect of group (F (1,28) = 0.675, p = 0.418, η^2 = .024) with PD participants having a similar marginal mean error score (M = 4.47; SE = .51) to that of the control participants (M = 5.06; SE = .51). In contrast, there was a significant main effect of the loudness level (F (4,112) = 395.3, p = < 0.001, η^2 =.934). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 22. In general, a significant difference was found for each of the pairwise comparisons of the loudness levels and this is reflected in the general pattern involving a gradual increase in the error score as the loudness level increased from 60 to 80 dB.

Table 22

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels. These marginal means reflect a combination of the 2 conditions (2 and 3) and the 2 groups

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values				
			60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-.098	.354	-				
65 dB	2.633	.364	**<.001***	-			
70 dB	5.150	.417	**<.001***	**<.001***	-		
75 dB	7.325	.414	**<.001***	**<.001***	**<.001***	-	
80 dB	8.830	.422	**<.001***	**<.001***	**<.001***	**<.001***	-

** = significant at $p < 0.05$ (Adjustment for multiple comparisons: Bonferroni)*

There was a significant main effect of condition (F (1,28) = 48.02, p = < 0.001, η^2 =.632). This effect relates to a significantly lower error score for condition 2 (M =2.43; SE = 0.411) relative to condition 3 (M = 7.106; SE = 0.565).

It is important to note that the main effects for the group, loudness level, and condition factors need to be evaluated relative to any potential interactions. The group by loudness level interaction was not significant (F (4,112) = 2.42, p = 0.090, η^2 = .080). The group by condition interaction was not significant (F (1,28) = 2.43, p = 0.130, η^2 = .080). In contrast, the condition by loudness level interaction was significant (F (4,112) = 45.25, p = < 0.001, η^2 =.618). This significant interaction is illustrated in Figure 12 which shows that the previously described trend involving an increase in the error score as the loudness level increases was different for condition 2 relative to condition 3. In particular, condition 2 shows a more gradual increase in error scores (flatter slope) as loudness level increases while condition 3 shows a much greater increase in error scores (steeper slope) as loudness level increases.

In order to illustrate this condition by loudness level interaction in more detail, a post-hoc analysis related to the pairwise comparisons of condition differences at each loudness level was performed. These post-hoc results are presented in Table 23. The post-hoc analysis found a significant, condition 2 versus condition 3, difference in the error scores at each of the 5 loudness levels with the condition 3 error score always having a greater value than the condition 2 error score. The significant interaction is reflected in the finding that the mean difference (Mdiff) between condition 2 versus condition 3 gradually increased from the low 60 dB loudness level (Mdiff = 2.32; SE = .69) to the high 80 dB loudness level (Mdiff = 7.37; SE = .79).

Table 23

Post-hoc results related to the comparison of the marginal mean error scores for Condition 2 (C2) versus Condition 3 (C3) at each of the 5 loudness matching levels

	Condition 2		Condition 3		C2 – C3 difference score t-test		
Loudness Level	Mean	*SE*	Mean	*SE*	Mean difference	Standard error difference	*p value*
60 dB	-1.26	.47	1.06	.52	-2.32	.68	**.002***
65 dB	1.04	.42	4.22	.58	-3.18	.70	**<.001***
70 dB	3.01	.44	7.29	.61	-4.28	.67	**<.001***
75 dB	4.21	.52	10.43	.61	-6.22	.78	**<.001***
80 dB	5.14	.47	12.52	.67	-7.37	.79	**<.001***

** = significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

Finally, the 3-way interaction involving group by loudness level by condition was significant (F (4,112) = 3.12, p = 0.030, η^2 =.100). This interaction is illustrated in Figure 12 and Table 24 which show that during condition 2 the HCs had a significantly lower error score than was observed during condition 3. In contrast, during condition 2, the PDs only had a significantly lower error score than was observed during condition 3 for the 70, 75 and 80 dB levels. Unlike the HCs, the PDs showed no significant difference between condition 2 and 3 during the 60 and 65 dB levels. Thus, there was a difference in how the PDs and HCs performed during condition 2 versus condition 3 across the 5 loudness levels, but especially during the 60 and 65 dB levels.

Table 24

Post-hoc results related to the comparison of the mean error scores for Condition 2 (C2) versus Condition 3 (C3) at each of the 5 loudness matching levels for the PD group and HC group

PD Group	Condition 2		Condition 3		C2 – C3 difference score t-test		
Loudness Level	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	*p value*
60 dB	-1.42	2.40	-0.12	3.36	-1.29	0.97	**.192**
65 dB	1.43	2.40	3.12	3.52	-1.69	0.99	**.098**
70 dB	3.49	2.09	6.26	3.81	-2.76	0.95	**.007***
75 dB	4.45	2.67	9.60	3.45	-5.15	1.11	**<.001***
80 dB	5.33	2.21	12.55	4.09	-7.22	1.12	**<.001***
HC Group	Condition 2		Condition 3		C2 – C3 difference score t-test		
Loudness Level	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	*p value*
60 dB	-1.09	2.70	2.25	2.19	-3.34	0.97	**.002***
65 dB	0.64	2.23	5.32	2.72	-4.67	0.99	**<.001***
70 dB	2.51	2.74	8.32	2.83	-5.80	0.95	**<.001***
75 dB	3.97	3.04	11.26	3.26	-7.28	1.11	**<.001***
80 dB	4.94	2.91	12.48	3.19	-7.53	1.12	**<.001***

** = significant at $p < 0.05$ (Adjustment for multiple comparisons: Bonferroni)*

In summary, these results related to RQ7 indicate that there was a significant difference between condition 2 (the condition that involved loudness matching of external target stimuli presented from an audio monitor at a 2-meter distance and manually controlled response stimuli played back from an audio monitor near the participant (projected)) and condition 3 (the condition that involved loudness matching of external target stimuli presented from an audio monitor at a 2-meter distance and a self-vocalized speech response, projected to the 2-meter audio monitor target). Condition 2 (projected external response) was generally associated with significantly higher error scores than condition 3 (projected self-vocalized response). However, the significant 3-way interaction indicated that the PD and HC groups responded differently to these 2 conditions across the 5 loudness levels. In particular, there was a similar condition effect found for both groups during the higher loudness levels (70, 75, and 80 dB), but the lower loudness levels (60 and 65 dB) had different condition effects across the two groups. The PD group showed no significant difference between condition 2 and 3 during the 60 and 65 dB levels while the HC group showed a significant condition effect for these levels.

3.9 Speech Loudness Matching Condition 3 versus 4 (RQ 8): Is there a difference in the loudness matching of amplified (+10 dB) self-vocalized speech (condition 4) versus unamplified self-vocalized speech (condition 3) that are projected to a distant (2 metre) target location in IWPD and control participants?

The following section relates to a comparison of the results obtained for speech loudness matching condition 3 versus condition 4 and addressed RQ8. Condition 3 examined loudness matching of unamplified self-vocalized speech that was projected to a 2-metre target. Condition 4 examined loudness matching of amplified (+10 dB) self-vocalized, speech that was projected to a 2-metre target. Both conditions involved the PD and HC participants and 5 loudness levels (60, 65, 70, 75 and 80 dB) of target speech stimuli. The statistical method used to address this research question (RQ8) was the three-way repeated measures ANOVA that involved a group factor with two levels (PD vs HC), a loudness level factor with 5 levels (60, 65, 70, 75, and 80 dB), and a condition factor with 2 levels (condition 3 vs condition 4). The primary dependent (outcome) measure was the average error score which was determined by subtracting the response speech intensity (dB SPL) from the target speech intensity for each trial to obtain a per trial error score and then averaging these scores for each loudness level. Thus, RQ8 examined if there were differences in the error scores during the loudness matching of unamplified, projected, self-vocalized speech (condition 3) versus amplified, projected, self-vocalized speech (condition 4). In addition, this comparison of conditions was examined and compared in the PD and HC groups to determine if there were group by condition differences (an interaction).

The descriptive statistics and average group results related to the 2 conditions and the 5 loudness matching levels for both the PD and HC groups are shown in Table 25 and Figure 13.

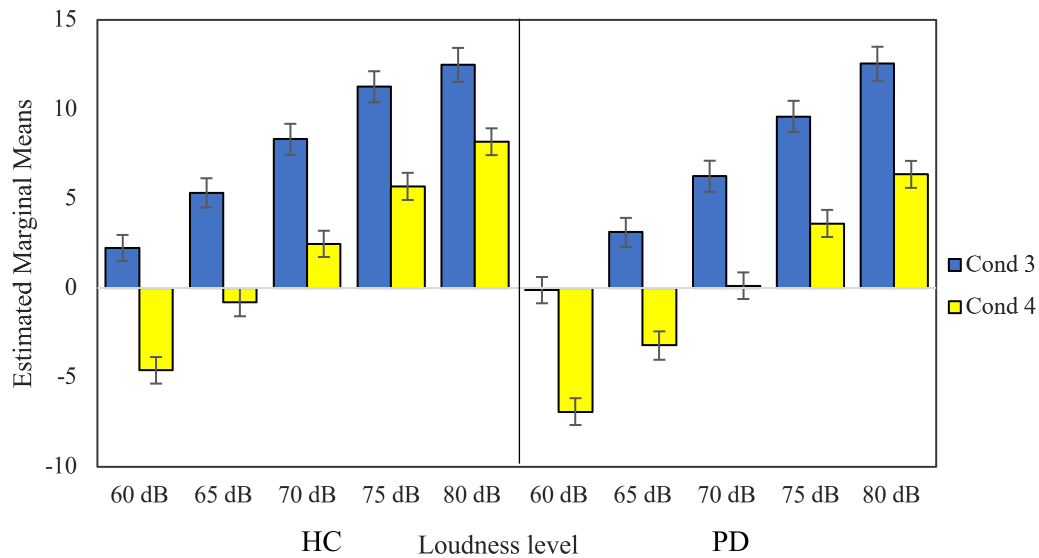
Table 25

Descriptive statistics for the error scores related to the 2 conditions (3 and 4) and the 5 loudness matching levels obtained for the PD and HC groups

Condition 3	PD		HC		Total	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-0.12	3.36	2.25	2.20	1.06	3.04
65 dB	3.12	3.52	5.33	2.73	4.23	3.29
70 dB	6.26	3.81	8.32	2.84	7.29	3.46
75 dB	9.61	3.45	11.26	3.27	10.43	3.41
80 dB	12.55	4.09	12.48	3.20	12.52	3.61
Condition 4	**PD**		**HC**		**Total**	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-6.91	3.45	-4.59	2.18	-5.75	3.07
65 dB	-3.22	3.75	-0.79	2.15	-2.01	3.25
70 dB	0.13	3.51	2.47	2.04	1.30	3.06
75 dB	3.61	3.44	5.69	2.39	4.65	3.09
80 dB	6.36	3.54	8.18	2.10	7.27	3.01

Figure 13

Mean error scores for the HC and PD groups obtained for the 5 loudness matching levels during condition 3 and condition 4. Error bars represent one standard error above and below the mean



The results of the three-way (condition by group by loudness level) ANOVA indicated that there was not a significant main effect of group (*F* (1,28) = 3.61, *p* = 0.068, η^2 = .114) with PD participants having a similar marginal mean (*M* = 3.14; *SE* = .71) to that of the control participants (*M* = 5.05; *SE* = .71). In contrast, there was a significant main effect of the loudness level (*F* (4,112) = 673.61, *p* = < 0.001, η^2 =.960). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 26. In general, a significant difference was found for each of the pairwise comparisons of the loudness levels and this is reflected in the general pattern involving a gradual increase in the error score as the loudness level increased from 60 to 80 dB.

Table 26

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels. These marginal means reflect a combination of the 2 conditions (3 and 4) and the 2 groups

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values				
			60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-2.34	.49	-				
65 dB	1.10	.52	**<.001***	-			
70 dB	4.29	.53	**<.001***	**<.001***	-		
75 dB	7.54	.53	**<.001***	**<.001***	**<.001***	-	
80 dB	9.89	.57	**<.001***	**<.001***	**<.001***	**<.001***	-

** = significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

There was a significant main effect of condition (F (1,28) = 302.17, p = < 0.001, η^2 =.915). This effect relates to a significantly higher error score for condition 3 (M =7.11; SE = 0.56) relative to condition 4 (M = 1.09; SE = 0.50). This result partially addresses RQ7 because it indicates that the 10 dB amplified condition (condition 4) was associated with lower error scores (about 6 dB better loudness matching) than the unamplified condition (condition 3) for both the PD and HC groups. The 3-way interaction results (see below) also indicate some group by level differences in these amplification condition effects.

It is important to note that the main effects for the group, loudness level, and condition factors need to be evaluated relative to any potential interactions. The group by condition interaction was not significant (F (1,28) = 0.63, p = 0.433, η^2 = .022). The group by loudness level was not significant (F (4,112) = 2.63, p = 0.079, η^2 =.086). In contrast, the condition by loudness level interaction was significant (F (4,112) = 6.39, p = <0.001, η^2 =.186).

In order to illustrate this condition by loudness level interaction in more detail, a post-hoc analysis related to the pairwise comparisons of condition differences at each loudness level was performed. These post-hoc results are presented in Table 27. The post-hoc analysis found a significant, condition 3 versus condition 4, difference in the error scores at each of the 5 loudness levels with the condition 4 error score always having a greater value than the condition 3 error score. The significant interaction is reflected in the finding that the mean difference (Mdiff) between condition 3 versus condition 4 gradually decreased from the 60 dB loudness level (Mdiff = 6.81; SE = .35) to the 80 dB loudness level (Mdiff = 5.24; SE = .38).

Table 27

Post-hoc results related to the comparison of the marginal mean error scores for Condition 3 (C3) versus Condition 4 (C4) at each of the 5 loudness matching levels

	Condition 3		Condition 4		C3 – C4 difference score t-test		
Loudness Level	Mean	*SE*	Mean	*SE*	Mean difference	Standard error difference	*p value*
60 dB	1.06	.52	-5.75	.52	6.81	.35	**<0.001***
65 dB	4.22	.58	-2.00	.55	6.23	.43	**<0.001***
70 dB	7.29	.61	1.30	.52	5.99	.39	**<0.001***
75 dB	10.43	.61	4.65	.54	5.78	.43	**<0.001***
80 dB	12.52	.67	7.27	.53	5.24	.38	**<0.001***

Finally, the group by loudness level by condition interaction was significant (F (4,112) = 2.82, p = 0.039, η^2 = .092). This interaction is illustrated in Figure 13 and Table 28 which show that, for the HC group, the condition 3 versus condition 4 difference in mean error scores decreases from the 60 dB to the 80 dB level (60 dB M = 6.84; 80 dB M

= 4.30). On the other hand, for the PD group, the condition 3 versus condition 4 difference in error scores remain about the same from the 60 dB to the 80 dB level (60 dB M = 6.78; 80 dB M = 6.19). In addition, the PD and HC groups appear to show a condition difference during the 60 dB and 65 dB levels. In particular, the PD group showed a greater shift from positive error scores to negative error scores during the 60 dB and 65 dB levels than was seen for the HC group. This indicates that the amplification condition caused the matching response to have higher intensity than the target during the 60 dB and 65 dB levels and that PD group had a higher intensity than the HC group during these two levels. Thus, these results indicate that the amplification condition was associated with 1) lower error scores (better loudness matching) in both groups, 2) matching responses that were greater than the target intensity during levels 60 and 65 dB, and 3) higher intensity matching responses for the PD group relative to the HC group during the 60 dB and 65 dB levels.

Table 28

Post-hoc results related to the comparison of the mean error scores for Condition 3 (C3) versus Condition 4 (C4) at each of the 5 loudness matching levels for the PD group and HC group

PD Group	Condition 3		Condition 4		C3 – C4 difference score t-test		
Loudness Level	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	*p value*
60 dB	-0.12	3.36	-6.91	3.45	6.78	.50	**<.001***
65 dB	3.12	3.52	-3.21	3.75	6.34	.60	**<.001***
70 dB	6.26	3.81	0.13	3.51	6.13	.55	**<.001***
75 dB	9.60	3.45	3.61	3.44	5.99	.61	**<.001***
80 dB	12.55	4.09	6.36	3.54	6.19	.54	**<.001***
HC Group	Condition 3		Condition 4		C3 – C4 difference score t-test		
Loudness Level	Mean	*SD*	Mean	*SD*	Mean difference	Standard error difference	*p value*
60 dB	2.25	2.19	-4.59	2.18	6.84	.50	**<.001***
65 dB	5.32	2.72	-0.79	2.15	6.12	.60	**<.001***
70 dB	8.32	2.83	2.47	2.04	5.85	.55	**<.001***
75 dB	11.26	3.26	5.68	2.38	5.57	.61	**<.001***
80 dB	12.48	3.19	8.18	2.09	4.30	.54	**<.001***

** = significant at $p < 0.05$ (Adjustment for multiple comparisons: Bonferroni)*

3.10 Speech Loudness Matching Condition 4 versus 5 (RQ 9): Is there a difference in the loudness matching of amplified projected (condition 4) versus amplified unprojected (condition 5) self-vocalized speech in PD and HC groups?

The following section relates to a comparison of the results obtained for speech loudness matching condition 4 versus condition 5 and addressed RQ9. Condition 4 examined loudness matching of amplified self-vocalized speech that was projected to a 2-metre target. Condition 5 examined loudness matching of unprojected, self-vocalized, and amplified (+10 dB) speech. Both conditions involved the PD and HC participants and 5 loudness levels (60, 65, 70, 75 and 80 dB) of target speech stimuli. The statistical method used to address this research question (RQ9) was the three-way repeated measures ANOVA that involved a group factor with two levels (PD vs HC), a loudness level factor with 5 levels (60, 65, 70, 75, and 80 dB), and a condition factor with 2 levels (condition 4 vs condition 5). The primary dependent (outcome) measure was the average error score which was determined by subtracting the response speech intensity (dB SPL) from the target speech intensity for each trial to obtain a per trial error score and then averaging these scores for each loudness level. Thus, RQ9 examined if there were differences in the error scores during the loudness matching of projected, amplified, and self-vocalized speech (condition 4) versus unprojected, amplified, and self-vocalized speech (condition 5). In addition, this comparison of conditions was examined and compared in the PD and HC groups to determine if there were group by condition differences (an interaction).

The descriptive statistics and average group results related to the 2 conditions and the 5 loudness matching levels for both the PD and HC groups are shown in Table 29 and Figure 14.

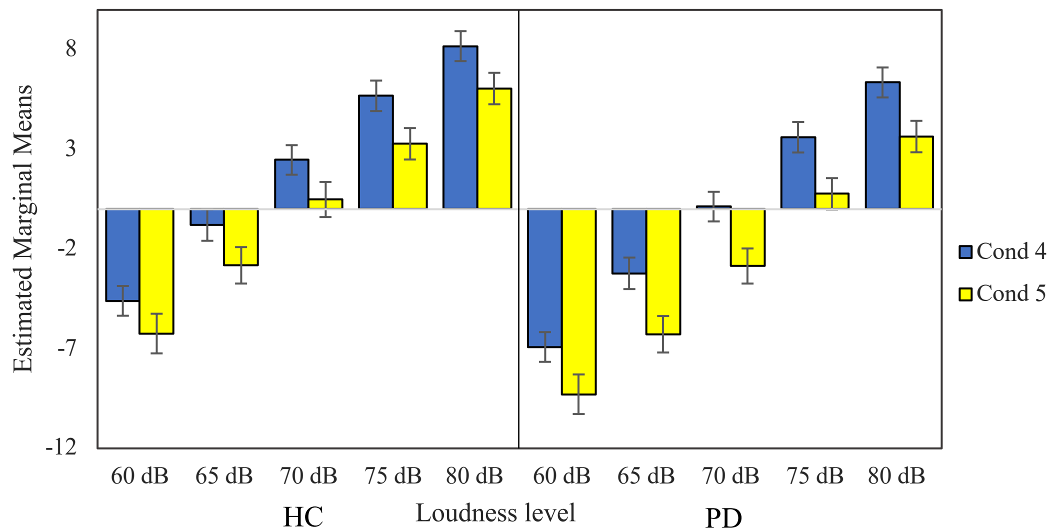
Table 29

Descriptive statistics for the error scores related to the 2 conditions (4 and 5) and the 5 loudness matching levels obtained for the PD and HC groups

Condition 4	PD		HC		Total	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-6.91	3.45	-4.59	2.18	-5.75	3.07
65 dB	-3.22	3.75	-0.79	2.15	-2.01	3.25
70 dB	0.13	3.51	2.47	2.04	1.30	3.06
75 dB	3.61	3.44	5.69	2.39	4.65	3.09
80 dB	6.36	3.54	8.18	2.10	7.27	3.01
Condition 5	**PD**		**HC**		**Total**	
Loudness Level	Mean	*SD*	Mean	*SD*	Mean	*SD*
60 dB	-9.28	3.45	-6.24	4.21	-7.76	4.09
65 dB	-6.27	3.15	-2.81	3.90	-4.54	3.90
70 dB	-2.85	3.41	0.49	3.41	-1.18	3.75
75 dB	0.77	2.88	3.28	3.22	2.03	3.26
80 dB	3.65	3.07	6.05	3.03	4.85	3.24

Figure 14

Mean error scores for the HC and PD groups obtained for the 5 loudness matching levels during condition 4 and condition 5. Error bars represent one standard error above and below the mean



The results of the three-way (condition by group by loudness level) ANOVA indicated that there was a significant main effect of group (F (1,28) = 6.55, p = 0.016, η^2 = .190) with PD participants having a significantly different marginal mean (M = -1.40; SE = .71) to that of the control participants (M = 1.17; SE = .71). Additionally, there was a significant main effect of the loudness level (F (4,112) = 879.01, p = < 0.001, η^2 =.969). A post-hoc analysis was used to examine the pairwise comparisons related to the 5 loudness levels. The results of these pairwise post-hoc comparisons are shown in Table 30. In general, a significant difference was found for each of the pairwise comparisons of the loudness levels and this is reflected in the general pattern involving a gradual increase in the error score as the loudness level increased from 60 to 80 dB.

Table 30

Post-hoc results related to pairwise comparisons involving the marginal means for the 5 loudness levels. These marginal means reflect a combination of the 2 conditions (4 and 5) and the 2 groups

Feedback Conditions	Mean	*SE*	Pairwise comparisons and p values				
			60 dB	65 dB	70 dB	75 dB	80 dB
60 dB	-6.758	.557	**-**				
65 dB	-3.275	.536	**<.001***	**-**			
70 dB	.060	.530	**<.001***	**<.001***	-		
75 dB	3.339	.507	**<.001***	**<.001***	**<.001***	-	
80 dB	6.061	.498	**<.001***	**<.001***	**<.001***	**<.001***	-

** = significant at p < 0.05 (Adjustment for multiple comparisons: Bonferroni)*

There was a significant main effect of condition (F (1,28) = 31.07, p = < 0.001, η^2 =.526). This effect relates to a significantly higher error score for condition 4 (M =1.093; SE = 0.502) relative to condition 5 (M = -1.322; SE = 0.589).

It is important to note that the main effects for the group, loudness level, and condition factors need to be evaluated relative to any potential interactions. The group by loudness level interaction was not significant (F (4,112) = 1.06, p = 0.352, η^2 = .037). The group by condition interaction was not significant (F (1,28) = 0.764, p = 0.389, η^2 = .027). The group by loudness level by condition interaction was not significant (F (4,112) = 0.263, p = .811, η^2 = .009). The condition by loudness level interaction was not significant (F (4,112) = 0.905, p = .426, η^2 =.031). Additionally, the group by loudness level by condition interaction was not significant (F (4,112) = 0.263, p = 0.811, η^2 = .009).

In summary, these results related to RQ9 found that there was a difference in the loudness matching of amplified projected (condition 4) versus amplified unprojected (condition 5) self-vocalized speech in both the PD and HC groups. In particular, the unprojected, amplified loudness matching condition (condition 5) was associated with a lower error score than the error score that was found for the projected amplified condition (condition 4). However, the sign of the error scores may need to be given consideration in these RQ9 related results involving the 60 dB and 65 dB levels. For these two levels, the error scores are negative for both groups. In addition, these negative error scores are greater for condition 5 than the negative error scores found for condition 4. Thus, if the sign of the error score is ignored (i.e., the absolute error scores were used) in the results for the 60 dB and 65 dB levels, then the error score would be considered greater for condition 5 than for condition 4. On the other hand, the absolute error scores obtained for levels 70, 75 and 80 dB would be considered lower for condition 5 relative to condition 4. This inconsistency in the error scores for the lower levels (60 dB & 65 dB) relative to the higher levels (70, 75, 80 dB) may be related to the observation that the matching responses were typically higher than the target intensity during the 60 and 65 dB levels but they were typically lower than the target intensity during the 70, 75 and 80 dB levels.

Chapter 4

4. Discussion

This chapter begins with an overview of the current study's research questions, followed by a detailed explanation of the findings with integration from the current literature. Clinical implications, future research directions and limitations of the current study will then be presented at the end of this chapter.

4.1 Overview

The current study aimed to evaluate loudness perception of external and self-produced speech stimuli in IWPD and hypophonia. A series of five loudness matching conditions were used to evaluate loudness perception in both IWPD and HC participants. The current investigation provides new information about speech loudness perception in IWPD and contributes to the current understanding of hypophonia, or reduced speech intensity in PD. Based on previous studies that demonstrated abnormal perceptual ratings of speech loudness in IWPD, it was predicted that IWPD would also demonstrate abnormal responses in a perceptual study involving loudness matching procedures. It was also predicted that IWPD would demonstrate an abnormal pattern of responses across five different loudness matching levels and the five loudness matching conditions that were examined in this study. As presented in chapter 1, the research questions of the current study are the following:

RQ1: Is there a difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that is played back through a response audio monitor (loudspeaker) that is at the same location as an audio monitor playing the target stimuli?

RQ2: Is there a difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that is played back through a response audio monitor (loudspeaker) that must be projected from a location nearby the participant to a distant (2 metre) audio monitor playing the target stimuli?

RQ3: Is there a difference between IWPD and HC participants in the loudness matching of self-vocalized speech in response to target speech stimuli presented via an audio monitor that is located 2 metres from the participant (i.e., projected vocal response)?

RQ4: Is there a difference between IWPD and HC participants in the loudness matching of amplified (+10 dB), self-vocalized speech in response to target speech stimuli presented via an audio monitor that is located 2 metres from the participant (i.e. projected, amplified, vocal response)?

RQ5: Is there a difference between IWPD and HC participants in the loudness matching of amplified (+10 dB), self-vocalized speech that is output from a response audio monitor (loudspeaker) that is at the same location as an audio monitor playing the target stimuli (i.e. unprojected, amplified, vocal response)?

RQ6: Is there a difference in the loudness matching of speech stimuli played back from a projected (near-participant) audio monitor versus an unprojected audio monitor at the same location as the target in IWPD and control participants?

RQ7: Is there a difference in the loudness matching of speech stimuli played back via an audio monitor versus via self-vocalized speech in IWPD and control participants?

RQ8: Is there a difference in the loudness matching of amplified (+10 dB) versus unamplified self-vocalized speech that is projected to a distant (2 metre) target location in IWPD and control participants?

RQ9: Is there a difference in the loudness matching of amplified projected versus amplified unprojected self-vocalized speech in IWPD and control participants?

4.2 Loudness matching of external speech stimuli

The following section will address RQ 1 and RQ 2, which investigated the loudness matching of external speech stimuli.

4.2.1 Loudness matching of unprojected external speech stimuli

The first RQ of the present study investigated if there was a difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that was played back through a response audio monitor positioned at the same location as an audio monitor playing the target stimuli. Thus, this loudness matching condition involved unprojected external stimuli. Using a large volume control knob, participants were instructed to match the loudness of an external speech stimulus to that of a target stimulus. The results for this condition found that there was no significant main effect of group with PD participants having a similar marginal mean to that of the HC participants. In addition, the group by loudness level interaction was not significant. This indicates that the loudness matching of external speech stimuli for both the PD and HC groups was similar. Thus, there was no difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that was played back through a response audio monitor that was at same location as the audio monitor playing the target stimuli.

As previously mentioned, it was hypothesized that the PD group would have a higher error score than the HC group, due to previous literature finding evidence to support a perceptual deficit, related to the perception of external stimuli, in IWPD (Adams et al., 2010; Clark et al., 2014; Ho et al. 2000). A study by Clark et al. (2014) found that during a magnitude estimation task involving the loudness rating of external speech stimuli, the PD group rated loudness levels differently than that of the HC group. A similar study by DeKeyser et al. (2016) obtained a similar result. Due to these previous findings supporting a perceptual deficit for the perception of the loudness of external stimuli in PD, it was expected that the PD group would have a lower loudness response intensity, and a higher error score in comparison to the HC group. However, the findings of the current study contrast with these previous studies with there being no significant difference between the PD and HC groups related to the loudness matching responses for targets involving (unprojected) external stimuli.

4.2.2 Loudness matching of projected external speech stimuli

The second RQ of the present study investigated if there was a difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that was played back through a response audio monitor that was at a location near the participant and projected to the location of the target stimuli. Using a large volume control knob, participants were instructed to match the loudness of an external speech stimulus to that of a target stimulus. The results for this condition found that there was no significant main effect of group with PD participants having a similar marginal mean to that of the HC participants. In addition, the group by loudness level interaction was not significant.

This indicates that the loudness matching of external speech stimuli for both the PD and HC groups was similar. Thus, there was no difference between IWPD and HC participants in the loudness matching of pre-recorded speech stimuli that was played back through a response audio monitor that was projected from a location nearby the participant to a distant (2 metre) audio monitor playing the target stimuli.

As discussed in the previous section, it was hypothesized that the PD group would have a higher error score in comparison to the HC group, due to previous evidence indicating a perceptual deficit related to the loudness perception of external stimuli in PD (Adams et al., 2010; Clark et al., 2014; Ho et al. 2000; DeKeyser et al. 2016). Additionally, it was hypothesized that inclusion of a projection requirement would further increase the error scores for the PD group, based on previous literature that found PD do not project their speech as effectively as HC due to an impairment in the perception of projection distance (Ehgoetz Martens et al., 2013). However, the findings of the current study contrast with these previous studies, as there was no significant difference between PD and HC groups related to the loudness matching response for targets involving projected external stimuli.

4.2.3 Summary of loudness matching of projected and unprojected external speech stimuli

RQ 1 and RQ2 were intended to investigate the role of loudness perception of external stimuli in hypophonia. As there were no significant findings between groups in either condition, this does not appear to provide support for the hypothesis of a deficit in the loudness perception of external speech stimuli having a causal role in the low speech intensity or hypophonia in IWPD. However, it is possible that the loudness matching of external speech stimuli may be insensitive to a loudness perception deficit. It is also possible that the processes involved in the loudness matching of external stimuli could remain intact despite the presence of a loudness perception deficit. In this interpretation, loudness matching processes would be considered separate and potentially dissociated from processes involved in the estimation of loudness level. This potential separation of loudness matching processes from loudness estimation processes needs to be verified in future studies of hypophonia and PD. In particular, it may be useful to conduct a future study that includes and compares both loudness matching conditions and loudness rating conditions for the same external stimuli.

These findings are in contrast to those found by Clark et al. (2014) and De Keyser et al. (2016) which also investigated perceptual deficits in IWPD and hypophonia. These studies used a magnitude estimation/rating task in which participants were to assign values to stimuli of various loudness levels. The contrast of results between the present study to those of Clark et al. (2014) and De Keyser et al. (2016), may be due to the difference in methods. Neither study used a loudness matching procedure, which may potentially account for the differences seen between these previous studies and the present study. In addition, there were across study differences in the task response procedures. The previous loudness rating studies involved producing a simple vocal motor response (saying a number that corresponds to the loudness rating) in response to a loudness stimulus while the matching procedure used in the present study involved producing a more complex manually controlled auditory-motor response to match the loudness of the target stimulus.

The finding that IWPD may have the ability to accurately match loudness stimuli despite having an impairment in the estimation of the loudness of external stimuli may have important implications for the development of treatment procedures for hypophonia.

Perhaps it would be possible to develop treatment procedures that take advantage of intact loudness matching processes in the retraining (also referred to as re-calibration) of abnormal loudness estimation processes in the treatment of hypophonia in PD.

The finding that there was no significant group difference in either the unprojected or projected condition indicates that the IWPD showed loudness matching of external stimuli that was comparable to the controls regardless of the speech projection (projected versus unprojected) requirements in this study. This finding suggests that the loudness matching of projected external stimuli may be intact in IWPD, and may be of potential importance for the development of future treatment procedures for hypophonia. One aspect of hypophonia that has been found to be abnormal is the speech intensity produced by IWPD at different talker-to-listener distances or projection distances (Ho, Iansek et al. 1999; Adams et al. 2010). IWPD have been found to have abnormally low speech intensity across different projection distances. The facilitating effects of loudness matching of projected external stimuli should be considered in improving hypophonia across different projection distances.

4.3 Loudness matching of projected, self-vocalized speech

The following section will address RQ 3 which investigated the loudness matching of self-vocalized speech.

The third RQ of the present study investigated if there is a difference between IWPD and HC participants in the loudness matching of unamplified, self-vocalized speech that is projected to the target stimuli. This involved an imitation task, in which the participant was asked to match the loudness of a target sound by using their voice to attempt to produce the same speech loudness.

There was no significant main effect of group with PD participants having a similar marginal mean to that of the HC participants. Thus, there was no difference between IWPD and HC participants in the loudness matching of self-vocalized speech in response to target speech stimuli presented via an audio monitor that was located 2 metres from the participant. However, there was a significant group by loudness level interaction which was related to an increasing difference between the PD and HC response error scores as the imitation target shifted from 80 dB down to 60 dB. For the 80 dB imitation target the PD and HC groups had response error scores that were not significantly different. As the imitation target shifted from 75 dB to 60 dB the response error scores for the PD group became progressively smaller (closer to the target) than those of the HC group. At the 60 dB target the error score for the PD group was significantly smaller than that of the HC group. This progression from a similar group performance at the 80 dB target to a significantly different group performance at the 60 dB target found in the present study is the complete opposite of the results that were found in two previous imitation studies by Clark et al. (2014) and DeKeyser et al. (2016). In both studies the difference between the group performance progressively increased as the target imitation intensity increased to 80 dB. In addition, in the Clark et al. (2014) study all the 5 loudness imitation levels were associated with the PD group having a lower response intensity than the control group. In contrast, the present study found that for most (4/5) of the 5 loudness imitation levels the PD group had a higher response intensity than the control group. Thus, the present findings indicating that the PD group had more accurate intensity imitation and higher imitation response intensity than the control group was unexpected and in complete contrast to the two previous speech loudness imitation studies in PD. The differences found from the aforementioned studies may be due to inconsistencies in study set-ups and the order of the study conditions. These differences will be discussed in more detail in section 4.10.

4.4 Loudness matching of amplified and self-vocalized speech

The following section will address RQ 4 and RQ 5 which investigated the loudness matching of amplified, self-vocalized speech.

4.4.1 Loudness matching of projected and amplified speech

The fourth RQ of the present study investigated if there is a difference between IWPD and HC participants in the loudness matching of amplified, self-vocalized speech that is projected to the target stimuli. This involved an imitation task, in which the participant was asked to match the loudness of a target sound by using their self-vocalized speech with a constant +10 dB amplification as the matching response.

There was a significant main effect of group with PD participants having a significantly lower mean error score than that of the HC group. Thus, there is a difference between IWPD and HC participants in the loudness matching of amplified (+10 dB), self-vocalized speech in response to target speech stimuli presented via an audio monitor that was located 2 metres from the participant. In particular, the PD group had a more negative mean matching error score, and the HC group had a more positive mean error score. Thus, the PD group showed greater intensity than the HC group during the amplified speech loudness matching condition. More specifically, the PD group showed greater intensity than the HC group at all of the loudness levels. However, this higher intensity had different effects on the matching accuracy across the loudness levels. In particular, the higher loudness levels (e.g. 70, 75 and 80 dB) were associated with positive error scores for both groups but the PD group had lower error scores than the HC group. Thus, for the higher loudness levels, the PD group appears to show more accurate loudness matching than the HC group. In contrast, the lower loudness levels (e.g. 60 and 65 dB) were associated with negative error scores for both groups, but the PD group had more negative error scores than the HC group. Thus, for these lower loudness levels both groups demonstrated a response intensity that was greater than the target intensity. This reflects a response overshoot of the target, and this overshoot was greater for the PD group than for the HC group. These group differences in the response intensity and response accuracy that appear to be dependent on the low versus high target levels, need to be further examined in future loudness matching studies of amplified self-vocalized speech.

4.4.2 Loudness matching of unprojected and amplified speech

The fifth RQ of the present study investigated if there is a difference between IWPD and HC participants in the loudness matching of amplified, self-vocalized speech that is unprojected. This involved an imitation task, in which the participant was asked to match the loudness of a target sound by using their self-vocalized speech with a constant +10 dB amplification as the matching response. The amplified self-vocalized speech was played through an audio monitor at the same 2-metre distance as the target stimulus, making it an unprojected condition.

There was a significant main effect of group with PD participants having a significantly smaller mean error score than that of the HC group. In particular, the PD group had a more negative mean matching error score, whereas the HC group had a positive, near zero mean error score, indicating the PD group used a higher response intensity than that of the HC group. Thus, there is a difference between IWPD and HC participants in the loudness matching of amplified (+10 dB), self-vocalized speech that was output through a response audio monitor that was at the same location as an audio monitor playing the target stimuli.

4.4.3 Summary of loudness matching of amplified speech

Previous literature on the effect of amplification on one's self-perception of speech is lacking. As such, the amplification condition was intended to investigate the effort deficit hypothesis in IWPD and hypophonia. It was hypothesized that if hypophonia was associated with a deficit in the scaling and judgement of speaking effort, then the PD group would be expected to perform similarly to the HC group during the amplification conditions. This expectation was related to the notion that when speech was given a constant boost of +10 dB of amplification, there would be a large reduction in the effort level required to imitate the target loudness levels presented in the experiment. The present study found that in both unprojected, and projected amplification conditions, the PD group was significantly louder on average in comparison to the HC group. These results provide support for the effort deficit hypothesis in IWPD and hypophonia. These results are consistent with that of a study by Soloman and Robin (2005), in which they investigated the perception of effort in IWPD. These researchers found that IWPD had an abnormally higher perception of effort when compared to HC participants (Soloman and Robin, 2005). In the current study, the PD group may have experienced a reduction in the effort required during the amplified conditions, and this may have directly contributed to their relatively higher speech intensity than the HC group. This finding of evidence supporting the effort deficit hypothesis provides important information for effort-based treatments such as LSVT. This popular behavioural treatment method uses phonatory effort and self-monitoring to improve affected parameters of speech in PD such as reduced loudness (Ramig et al., 2004). The present study's findings contribute to the theoretical basis of this treatment and furthers the understanding of how to best design and implement effort based treatments such as LSVT through the significant differences found between external, self-generated and amplified speech loudness matching. Clinical implications of effort-based treatment and the loudness matching procedure used in the present study will be discussed further in section 4.11.

4.5 Comparison of loudness matching of projected versus unprojected external speech stimuli

In RQ 6, the results of condition 1 were compared to the results of condition 2 via a three-way ANOVA, to investigate any potential differences between the matching of *unprojected* external speech stimuli (condition 1), and the matching of *projected* external speech stimuli (condition 2). There was no significant main effect of group with PD participants having a similar marginal mean to that of the control participants. However, there was a significant main effect of condition, with the projected condition having a significantly higher error score relative to the unprojected condition.

This result indicates that it was more difficult for both groups to accurately match external loudness targets when the requirement of projecting the response was added to the task conditions. It may be of potential importance, that the IWPD showed similar loudness matching performance to that of the controls during the more difficult projected response condition. This suggests that the processes involved in the projection of manually controlled external stimuli appears to have been intact in these IWPD during these loudness matching conditions. This result may have important implications related to the projection estimation abilities in PD. This result seems to suggest that the processes involved in the estimation and control of sound projection may be different from the processes involved in the projection of self-vocalized speech. This potential separation of projection processes will be discussed in the section 4.8.

4.6 Comparison of external versus self-vocalized speech

In RQ 7, the loudness matching results for projected self-vocalized speech (condition 3) were compared to the results for projected external speech stimuli (condition 2) using a three-way ANOVA. Results of the ANOVA revealed a significant condition effect, indicating that the projected self-vocalized speech condition had a significantly greater error score than the projected external speech stimuli. The ANOVA also found a significant condition by loudness level interaction, indicating that as the loudness target levels increased from 60 to 80 dB there was an increasing difference between the error scores obtained for the 2 conditions. In particular, as the target loudness level increased the error scores for the projected self-vocalized condition gradually became greater than the error scores for the projected external stimuli. This greater increase in error scores for the self-vocalized condition may be related to a relatively greater effort level required to reach the higher intensity/loudness levels during self-vocalized speech relative to the lower effort level needed for the externally produced speech.

The group by loudness level by condition 3-way interaction was also found to be significant and indicated that for the higher loudness target levels (70, 75 and 80 dB) both groups showed similar condition effects with the self-vocalized matching condition showing greater error scores than the external speech matching condition. However, at the lower loudness targets levels (60 and 65 dB) the group results diverged. At these lower loudness levels, the HC group continued to show greater error scores for the self-vocalized condition than the external speech condition. However, for these low loudness levels, the PD group showed the same error scores for the self-vocalized and external stimuli conditions.

This indicates that for these low loudness levels the PD group showed matching performance that was similar for self-generated speech and external speech stimuli. This result would appear to support an effort explanation in findings for the PD group. In particular, at the low target levels the effort level would be expected to be relatively low for the self-vocalized condition and comparable to the effort level for the external stimuli condition. As a result, the error scores would be expected to be similarly low for both conditions during the low loudness targets. As the loudness levels increased there would be expected to be an increase in the effort level for the self-vocalized condition but not the external stimuli condition. This increase in effort would be expected to produce an increase in the error scores for the self-vocalized condition relative to the external condition in the PD group.

No previous studies have conducted a direct comparison of the perception of self-vocalized speech loudness and external speech loudness in IWPD. In a study by Clark et al. (2014), the perception of external and self-produced loudness levels was examined separately using a ME task and an imitation task respectively. While not compared statistically, an informal evaluation of the Clark et al. (2014) study appears to indicate that, relative to their HC group, the PD group had a greater deficit in the self-vocalized loudness perception task than was observed in the external speech loudness perception task (Clark et al., 2014). Thus, these previous informal findings appear to generally support the more formal statistical results observed in the present study and especially for the higher loudness level targets (70, 75 and 80 dB). Regarding the lower loudness target levels (60 and 65 dB), the Clark et al. (2014) study did not appear to show that IWPD had similar perceptual results for the self-vocalized and external speech perception tasks such as was found in the present study. However, as mentioned previously, the Clark et al. (2014) study did not do a formal statistical comparison of the two conditions. Additionally, De Keyser et al. (2016) found that the PD group only differed from the HC group during the higher loudness levels for both tasks (75 and 80 dB for the estimation task, 80 dB for the imitation task). This contrasts with the findings of the current study in which the HC and PD groups diverged at the lower loudness levels in the respective tasks.

4.7 Comparison of unamplified versus amplified self-vocalized speech

RQ 8 involved a comparison of the results of the matching of unamplified speech condition (condition 3) and the results of the amplified speech condition (condition 4). The purpose of this RQ was to investigate the hypothesis of an effort deficit in IWPD and hypophonia. It was hypothesized that if IWPD performed better in the amplification condition, then this would provide support for the effort deficit hypothesis as the amplification was intended to reduce the effort requirement for loudness matching.

There was no significant main effect of group with PD participants having a similar average loudness matching error score to that of the control participants. However, there was a significant main effect of condition with the unamplified speech loudness matching condition having a significantly higher error score relative to the amplified speech loudness matching condition. Thus, there was a difference in the loudness matching of amplified (+10 dB) versus unamplified self-vocalized speech that is projected to a distant (2 metre) target location in IWPD and control participants, with the unamplified condition having a higher error score compared to the amplified condition. Furthermore, lower intensity levels (60 dB and 65 dB) had a negative mean error score, indicating that the participants produced speech intensity responses with greater speech intensity than the target speech intensity for these lower loudness matching levels. Additionally, when considering the groups respectively during these lower loudness levels, the PD group had higher intensity matching responses relative to the HC group. Therefore, these results for the PD group, showing improvement in loudness matching when amplification was introduced and higher speech intensity than controls during some loudness levels, appears to provide support for the effort deficit hypothesis in the hypophonia of PD.

As previously discussed, Soloman and Robin (2005) found evidence to support an effort deficit in IWPD and hypophonia. It was suggested that IWPD may perceive effort differently than HC and that this may influence speech intensity. In particular, it is hypothesized that IWPD and hypophonia underestimate the effort that is required to achieve the desired or required speech intensity level. The results related to RQ8 in the present study appear to be consistent with the effort deficit results reported in the Soloman and Robin (2005) study. As previously mentioned, the effort deficit hypothesis is a key component of the LSVT program for the treatment of hypophonia. Thus, the present results related to RQ8 appear to provide support for the current LSVT program. The present results may have implications for the development of new treatments that enhance or refine the effort-based aspects of the treatment procedures. One potential direction for this refinement may involve the use of speech amplification procedures in behavioural, effort-focused treatment programs for hypophonia.

4.8 Comparison of projected versus unprojected amplified self-vocalized speech

RQ 9 involved a comparison of the matching of projected amplified speech condition (condition 4) and the unprojected amplified speech condition (condition 5). The purpose of this RQ was to investigate the role of projection in IWPD and hypophonia.

There was a significant main effect of group, with PD participants having a significantly lower average loudness matching error score than the control participants. This group effect was previously discussed in the sections related to RQ4 and RQ5. More relevant to RQ9 was the finding that there was a significant main effect of condition. In particular, the projected amplified speech loudness matching condition (condition 4) had a significantly higher error score than the unprojected amplified speech matching condition (condition 5). These findings along with those in section 4.5 both indicate that there was an effect of the projection condition on the loudness matching performance with the addition of the projection requirement causing an increase in error score for both the matching of external speech loudness and the matching of self-vocalized speech loudness. These results suggest that the introducing projection requirements into the loudness matching paradigm reduces the accuracy of matching performance. One potential explanation for this projection effect is that the addition of the projection requirement makes the loudness matching task more cognitively demanding and that this causes a decrease in performance accuracy. The increase in cognitive demand associated with projection is assumed to be related to the additional cognitive requirements involved in estimating the effect of distance on intended or predicted intensity. This perceptual-motor estimation of intended intensity versus distance is part of the well described interlocutor distance effect found in everyday communication (Healey et al. 1997). Interestingly, there have not been any previous attempts to measure the cognitive demands associated with the interlocuter distance effect. However, in the present study it is proposed that the combined cognitive demands of the matching task and the projection task may be responsible for the greater matching error score for the projected conditions versus the unprojected conditions.

The failure to find a significant 2-way or 3-way interaction related to RQ9 indicates that the projection effect found in these amplified self-vocalized conditions was similar across groups and loudness levels. The failure to find a group difference for the projection effect is somewhat unexpected and in contrast to previous studies of interlocuter distance effects on speech intensity in PD. Previous studies of interlocuter distance in PD have found that IWPD consistently underestimate the appropriate speech intensity across various interlocuter distances (Adams et al., 2010; Ho, Iansek et al., 1999; McCaig et al., 2015). One potentially important difference between these previous studies and the current one relates to the participants' intended speech intensity target or goal. In the previous studies, the intended speech intensity target or goal was the participant's internal target of the speech intensity that was required to be heard by the listener. So, this intensity target was determined by the participant. In the present loudness matching study, the participant was provided with an external intensity target. Thus, the participant was not required to estimate the target. So, in the present study the participant did not have to determine if the target intensity was appropriate to the projection distance as was the case in the previous interlocuter distance studies. Thus, these inconsistencies may be related to differences in between loudness matching process versus loudness estimation processes. As previously discussed, these processes are hypothesized to be separate and differentially impaired in IWPD and hypophonia.

It should be noted that RQ9 explored the projection effect in the context of amplified speech only. Future studies are required to explore the projection effect on loudness matching in unamplified speech. However, it may be challenging to incorporate a condition that involves unprojected self-vocalized speech. Perhaps the systematic manipulation of projection distance and amplification level could be used to explore the role of projection in effect in future studies of loudness perception in PD.

4.9 Enhanced loudness matching in PD

The results of the current study contrast the predicted outcome. It was predicted that the PD group would consistently show a higher error score, or a lower intensity than the target, across conditions when compared to the HC group. However, the PD group often produced higher intensity responses than the HC group. Therefore, a more intense than normal, or *enhanced* response was seen within this PD study group. The following section will detail possible suggestions as to why this enhanced response occurred.

A study by Clark et al. (2014) investigated similar perceptual phenomena in IWPD and hypophonia. A magnitude estimation task found that the PD group rated 60 dB and 65 dB as louder than the HC group but rated the 75 dB and 80 dB loudness levels as quieter than the HC (Clark et al. 2014). These findings align with that of the current study, in which a restricted loudness range was found in various conditions for the PD group in comparison to the HC group. This restricted loudness range may contribute to the decrease in error score for the PD group at the lower loudness level (60 dB and 65 dB) as they are not perceiving, and therefore adjusting, their speech intensity to the intended lower loudness target.

The results from the imitation task from Clark et al. (2014) contrast those of the current study. It was found that the PD group had a lower speech intensity in comparison to the HC group across all loudness conditions (Clark et al., 2014). In the current study, the PD group often had a lower, or more negative error score in comparison to the HC group, indicating that they often had higher intensity than the HC group. These contrasting findings could be the result of a difference in the physical set up of the two studies. For example, the Clark et al. (2014) study used a similar set-up but with nearly half of the projection distance that was used in the current study (120 cm distance vs. 200 cm distance). Thus, projection distance may have played a role in the across study differences. This set up parameter could be systematically investigated in future studies. The current study focused on the same speech stimulus "I owe you a yo-yo", and this sentence was continuously used across all study conditions. This may have reduced the mental load of focusing on the content of conversation and allowed for more focus on the loudness level being presented. As suggested by Ho, Iansek et al. (1999), having more focus on the content of the speech as would be seen in conversation, may result in a lesser focus on intensity. Whereas in the current study, the majority of the focus would have been on the loudness levels and this may have been easier to perceive. This is further supported by a finding from De Keyser et al. (2016), which found that during propositional, or spontaneous speech, a lower speech intensity was found in the PD group in comparison to the HC group, where non propositional speech did not find this difference. It was suggested by the authors that an automatic monitoring deficit may be associated with PD (De Keyser et al., 2016). Therefore, future studies should investigate the loudness matching of conversational speech in comparison of predictable speech. This variation in the speech task could be considered as part of additional manipulations of the cognitive demands of the loudness matching paradigm in future studies. A final consideration related to an explanation for the enhanced loudness matching found for the PD group during the self-vocalizing conditions relates to an order effect involving the manually controlled external matching conditions preceding the self-vocalized matching conditions. This potential order effect is also seen as an important limitation of the study and will be discussed in the next section.

4.10 Limitations to the current study

Potential limitations of this study include use of a constant condition order in all the study sessions. The 2 conditions involving the loudness matching of external speech stimuli using a volume control knob always preceded the loudness matching of self-produced speech, and thus causes concern for an order effect biasing the results. As the study started with a hand-based motor task to match the loudness levels, there is a possibility of cross-system motor priming effect that occurred prior to the self-vocalized conditions (i.e., limb system priming or enhancing the speech/vocal system). Two previous studies involving concurrent limb and speech tasks have reported an enhancing effect of the limb motor task on the speech intensity in IWPD and hypophonia (Adams et al., 2010; McCaig et al., 2015). The Adams et al. (2015) study found that a concurrent task involving the squeezing of a hand bulb to track a visual target caused an increase in the speech intensity of a concurrent speech task. In the McCaig et al. (2015) study, concurrent walking and talking caused an increase in speech intensity in IWPD and hypophonia. The results of these two studies have been described as evidence of a potential enhancing or energizing effect of certain limb tasks on speech intensity in PD (McCaig et al., 2015). It should be noted that these previous studies involved concurrent limb and speech tasks instead of a sequential limb task followed by a speech task, such as occurred in the present study. Future studies are required to examine this sequential effect of limb tasks on speech intensity in IWPD and hypophonia.

Future evidence for a potential enhancing effect of limb tasks on speech tasks could emerge from the effects of combining limb treatment programs for hypokinesia in PD (i.e., LSVT BIG) with speech treatment programs for hypophonia in PD (i.e., LSVT LOUD) (Fox et al., 2012). Unfortunately, although the potential combinational effects of these well-established limb and speech treatments have been proposed, no evidence has been published.

Previous literature suggests that IWPD have a deficit in feedforward mechanisms, and thus heavily rely or over rely on feedback processes (Abur et al., 2018; Liu et al., 2012). The loudness matching tasks used throughout the present study may have been heavily weighted towards the evaluation of feedback processes rather than feedforward processes. If the matching tasks are considered to have primarily focused on feedback processes in loudness perception and production, and the IWPD were over-reliant on feedback processes this may have led to enhanced performance by the PD group relative to the control group. Thus, an over-reliance on feedback processes may have been associated with higher intensity responses or more accurate matching responses by the IWPD during the self-vocalized matching conditions. On the other hand, the manually controlled external speech matching conditions would not be expected to demonstrate this more accurate performance because the limb system of these PD participants may not be biased toward an over-reliance on feedback when it involves the use of auditory stimuli for an auditory-motor matching task. Thus, two potential explanations for the enhanced matching performance during the self-vocalized conditions relate to a motor priming effect that emerged from the order of the conditions or a possible over-reliance on and enhancement of feedback processes by the PD group during the self-vocalized conditions.

An additional limitation of the present study may include the imbalance of male vs. female participants in the PD vs. control groups. The PD group had slightly more male participants (67% male) whereas the HC group was predominantly female (80% female). Unfortunately, there is no evidence to indicate a sex effect on loudness perception and therefore this potential factor is inconclusive but may need to be examined in future studies.

Another potential limitation of the study was the severity of hypophonia demonstrated by the IWPD. It should be noted that all of the participants were identified by their neurologist as having hypophonia. In addition, an informal acoustic analysis of the conversational speech intensity found significantly lower speech intensity for the PD group relative to the HC group. However, the hypophonia severity of the PD group in the present study may have been milder than that of previous studies and this may have played a role in the across study inconsistencies. While it is difficult to make accurate comparisons of hypophonia severity across studies, an informal comparison of the present study and the Clark et al., (2014) study indicated that the current PD group had slightly less severe hypophonia.

Another factor that may need to be considered is the effect of the laboratory context or setting. In particular, the laboratory setting may have caused an overcompensation in speech intensity in the PD group. As the study had a large focus on loudness of speech, this may have caused PD participants to overcompensate their responses. Naturally, the PD group would have more experience in focusing on their loudness levels because of frequent requests from conversation partners to repeat themselves, and therefore may have had a heavier focus on increasing speech volume in comparison to the HC group, who likely focused very little on their speech volume in day-to-day life. In addition, the IWPD may have had concerns about their hypophonia, and this may have motivated them to demonstrate increased speech intensity (overcompensate for their hypophonia) during a research study that was clearly focused on the evaluation of hypophonia and self-loudness perception. It should be noted that previous studies conducted in the same lab setting have never been associated with a PD group showing significantly higher speech intensity than a control group. In fact, such a result has never been reported in a previous publication related to speech intensity in PD. In addition, it should be noted that following a brief search of the published studies in PD, only a few studies have ever reported better performance by a PD group relative to a control group. One example of this very rare occurrence relates to a study of creativity in PD. This study by Faust-Socher et al., (2014) found that a PD group demonstrated enhanced verbal and visual creativity as compared to neurologically healthy controls. Unfortunately, it is difficult to draw a connection between the enhanced creativity results of this previous study and the enhanced loudness matching results of the present study. However, both studies may be important because of the rarity of observing better performance by a PD group relative to a control group.

An additional consideration of the current study is the stimulus used "I owe you a yo-yo". This sentence was chosen as the study stimulus because it can be continuously voiced for the duration of the utterance, so that there would be expected to be no voice breaks. The absence of voice breaks was intended to reduce the within utterance variability in intensity and was therefore also assumed to result in a more accurate measurement of response intensity and the related matching error score. However, other potential sources of variability were possible and may have influenced the results. One potential source of variability is a downward or upward drift in intensity across the response utterance. A downward drift or declination in intensity can often be seen in the typical speech of healthy controls and has been reported to be excessive in IWPD in some previous studies (Rosen et al., 2005). An upward drift in response intensity is also possible in the loudness matching paradigm as part of the participant's dynamic attempts to achieve the desired response intensity. For example, if the participant produced the first words of the utterance at an intensity below their intended response and then increased their intensity towards the end of the utterance, the result would be an upward drift in intensity. Of course, other patterns of intensity variability are also possible. In the present study, the primary outcome measure focused on the mean intensity of the utterance and therefore the potential effect intensity variability on the loudness matching results was not examined. It is recommended that future studies consider examing these potential utterance variability effects on loudness matching performance. In addition, future studies could evaluate the effect of different phonetic components (e.g. voiced versus voiceless phonemes) in the target sentence on the accuracy of the loudness matching results.

4.11 Clinical implications

The current study provides more information regarding the mechanisms behind loudness perception in IWPD and hypophonia. Additionally, a potential implication for treatment enhancement may have been identified through the constant order of the experimental conditions. The use of hand-based motor priming could provide an enhancement to existing loudness treatments, such as LSVT, and should continue to be studied in the future. For example, the potential enhancing effects of sequentially or concurrently combining LSVT BIG with LSVT LOUD treatments should be examined in future clinical studies.

Additionally, the results of the present study provide support for the previously described effort deficit in IWPD and hypophonia and appear to provide support for effort-based treatments such as LSVT. The present study also suggests that speech amplification procedures should be considered in the development of future treatment procedures focused on enhancing the treatment of the effort deficits in IWPD and hypophonia.

4.12 Future research directions

Several future research directions have been mentioned at earlier points in this discussion chapter. The most important direction is judged to be the replication of the results that found that the PD group had more accurate performance than the HC group during the self-vocalized loudness matching conditions. During such a replication study, the effect of the order of the experimental conditions would need to be systematically evaluated to determine if the condition order influenced the results of the current study. If an order effect was found, then the nature of this order effect would need to be explored in future studies. In particular, the potential order effect of having a manual (limb motor) task influence a subsequent speech loudness/intensity task would need to be systematically explored.

As previously mentioned, the present study results provide support for the previously described effort deficit in IWPD and hypophonia and appears to provide support for effort-based treatments such as LSVT. The present study also suggest that speech amplification procedures should be considered in the development of future treatment procedures focused on enhancing the treatment of the effort deficits in IWPD and hypophonia.

The results of the present study indicate that introducing a requirement to project speech to a distant target influenced the accurate perception of the loudness of external speech and self-vocalized speech. Thus, future studies are needed to systematically explore the effects of projection and the effects of different projection distances on speech loudness perception in PD. Given that the introduction of projection requirements can be seen as a potential increase in cognitive demands during loudness matching procedures, it may be important to examine the effects of other cognitive demands on loudness match procedures. One such variation in cognitive demands might involve the use of more, or less, cognitively demanding speech tasks, such as the loudness matching of conversational speech versus the loudness matching of a single memorized sentence. An additional future direction could include determining the effects of hypophonia severity on loudness perception and the loudness matching of external and self-vocalized speech. As previously discussed, the severity of hypophonia for the PD participants in this study was relatively mild. Future studies may replicate the current methodology, including only participants with severe hypophonia and compare the results to the current study.

4.13 Summary and conclusion

This study used several speech loudness matching conditions to evaluate loudness perception in IWPD and hypophonia. Previous loudness scaling research provided support for a loudness perception deficit in PD. Based on this previous work, the PD group was predicted to demonstrate greater loudness matching error scores than the HC group. For most of the loudness matching conditions, the PD group did not demonstrate the predicted deficit in loudness matching. In some loudness matching conditions, the PD group had lower (more accurate) error scores than the HC group. More specifically, for most of the loudness matching conditions involving self-vocalized (imitation) responses, the PD group had significantly lower error scores than the HC group. This result is inconsistent with previous studies of speech loudness imitation in PD. In addition, the finding that a PD group had better performance than a HC group is judged to be unique in the field of speech perception and production. Factors that may have influenced this result include the ordering of experimental conditions, the facilitating effect of a preceding limb motor task, hypophonia symptom severity, and PD-related enhancement of feedback processes. Future studies are required to replicate and further examine these speech loudness matching results in IWPD and hypophonia.

In addition to group effects, the present study also found condition effects related to variations in the projection distance of loudness matching responses and variations in the amplification of self-vocalized speech matching responses. More specifically, increases in projection distance were associated with significantly greater loudness matching error scores and the introduction of speech amplification was associated with a reduction in loudness matching error scores in both the PD and HC groups. The improvement in loudness matching error score associated with speech amplification appears to provide support for an effort deficit hypothesis in the hypophonia of PD. It is recommended that amplification procedures be considered in future loudness perception studies and that amplification procedures be considered in future attempts to develop new treatment programs for hypophonia in PD.

References

Abbruzzese, G., & Berardelli, A. (2003). Sensorimotor integration in movement disorders. *Movement disorders: official journal of the Movement Disorder Society*, 18(3), 231–240. https://doi.org/10.1002/mds.10327

Abeyesekera, D. (2019). The Role of Auditory Feedback for Speech Intensity Regulation in Parkinson's Disease. *Electronic Thesis and Dissertation Repository*. 6405. https://ir.lib.uwo.ca/etd/6405

Abur, D., Lester-Smith, R. A., Daliri, A., Lupiani, A. A., Guenther, F. H., & Stepp, C. E. (2018). Sensorimotor adaptation of voice fundamental frequency in parkinson's disease. *PLOS ONE*, 13(1). https://doi.org/10.1371/journal.pone.0191839

Adams, S. G., & Dykstra, A. (2009). Hypokinetic dysarthria. In M. R. McNeil (Ed.), Clinical management of sensorimotor speech disorders. Thieme.

Adams, S. G., Dykstra, A., Jenkins, M., & Jog, M. (2008). Speech-to-noise levels and conversational intelligibility in hypophonia and Parkinson's disease. *Journal of Medical Speech - Language Pathology*, *16*(4), 165+. https://link.gale.com/apps/doc/A191480538/AONE?u=anon~b0e2b1a1&sid=googleScholar&xid=865f1307

Adams, S., Moon, B., Dykstra, A., Abrams, K., Jenkins, M., & Jog, M. (2006). Effects of multitalker noise on conversational speech intensity in Parkinson's disease. *Journal of Medical Speech-Language Pathology*, 14, 221-228.

Adams, S.G., Winnell, J., & Jog, M. (2010). Effects of interlocutor distance: multi-talker background noise, and a concurrent manual task on speech intensity in Parkinson's disease. *Journal of Medical Speech-Language Pathology*, 18(4), 1–8.

Almeida, Q. J., Frank, J. S., Roy, E. A., Jenkins, M. E., Spaulding, S., Patla, A. E., & Jog, M. S. (2005). An evaluation of sensorimotor integration during locomotion toward a target in Parkinson's disease. Neuroscience, 134(1), 283–293. https://doi.org/10.1016/j.neuroscience.2005.02.050

Andreetta, M. D., Adams, S. G., Dykstra, A. D., & Jog, M. (2016). Evaluation of speech amplification devices in Parkinson's disease. *American Journal of Speech-Language Pathology*, 25(1), 29+. http://dx.doi.org.proxy1.lib.uwo.ca/10.1044/2015_AJSLP-15-0008

Balestrino, R., & Schapira, A. H. V. (2020). Parkinson disease. *European Journal of Neurology*, 27(1), 27–42. https://doi.org/10.1111/ene.14108

Bloem, B. R., Okun, M. S., & Klein, C. (2021). Parkinson's disease. Lancet (London, England), 397(10291), 2284–2303. https://doi.org/10.1016/S0140-6736(21)00218-X

Bodden, M. E., Dodel, R., & Kalbe, E. (2010). Theory of mind in parkinson's disease and related basal ganglia disorders: A systematic review. *Movement Disorders*, 25(1), 13–27. https://doi.org/10.1002/mds.22818

Boller, F., Passafiume, D., Keefe, N. C., Rogers, K., Morrow, L., & Kim, Y. (1984). Visuospatial impairment in Parkinson's disease. Role of perceptual and motor factors. Archives of neurology, 41(5), 485–490. https://doi.org/10.1001/archneur.1984.04050170031011

Braak, H., Tredici, K. D., Rüb, U., de Vos, R. A. I., Jansen Steur, E. N. H., & Braak, E. (2003). Staging of brain pathology related to sporadic parkinson's disease. Neurobiology of Aging, 24(2), 197–211. https://doi.org/10.1016/s0197-4580(02)00065-9

Brajot, F.-X., Nguyen, D., DiGiovanni, J., & Gracco, V. L. (2018). The impact of perilaryngeal vibration on the self-perception of loudness and the Lombard effect. *Experimental Brain Research*, 236(6), 1713+. https://link.gale.com/apps/doc/A541044138/AONE?u=lond95336&sid=bookmark-AONE&xid=d22c8eea

Bruno, V., & de Freitas, M. E. T. (2019). Streamlining the management of Parkinson disease in Canada. *CMAJ : Canadian Medical Association journal = journal de l'Association medicale canadienne*, *191*(36), E979–E980. https://doi.org/10.1503/cmaj.191089

Bronstein, A. M., Hood, J. D., Gresty, M. A., & Panagi, C. (1990). Visual control of balance in cerebellar and parkinsonian syndromes. Brain : a journal of neurology, 113 (Pt 3), 767–779. https://doi.org/10.1093/brain/113.3.767

Chen, X., Zhu, X., Wang, E. Q., Chen, L., Li, W., Chen, Z., & Liu, H. (2013). Sensorimotor control of vocal pitch production in Parkinson's disease. *Brain Research*, 1527(Complete), 99–107. https://doi.org/10.1016/j.brainres.2013.06.030

Clark, J. P., Adams, S. G., Dykstra, A. D., Moodie, S., & Jog, M. (2014). Loudness perception and speech intensity control in parkinson's disease. *Journal of Communication Disorders*, 51, 1–12. https://doi.org/10.1016/j.jcomdis.2014.08.001

Coates, C., & Bakheit, A. M. (1997). The prevalence of verbal communication disability in patients with parkinson's disease. *Disability and Rehabilitation*, 19(3), 104–107. https://doi.org/10.3109/09638289709166834

Conte, A., Khan, N., Defazio, G., Rothwell, J. C., & Berardelli, A. (2013). Pathophysiology of somatosensory abnormalities in Parkinson disease. *Nature reviews. Neurology,* 9(12), 687–697. https://doi.org/10.1038/nrneurol.2013.224

Cushnie-Sparrow, D., Adams, S., Abeyesekera, A., Pieterman, M., Gilmore, G., & Jog, M. (2018). Voice quality severity and responsiveness to levodopa in parkinson's disease. *Journal of Communication Disorders*, 76, 1–10. https://doi.org/10.1016/j.jcomdis.2018.07.003

Darley, F.L., Aronson, A.E., & Brown, J.R. (1975). Motor speech disorders. Philadelphia: W.B. Saunders.

DeBonis, D. A., & Donohue, C. L. (2008). *Survey of audiology: Fundamentals for audiologists and health professionals* (2nd ed.). Boston, MA: Pearson Education.

De Groote, E., De Keyser, K., Bockstael, A., Botteldooren, D., Santens, P., & De Letter, M. (2020). Central auditory processing in Parkinsonian Disorders: A systematic review. *Neuroscience & Biobehavioral Reviews*, 113, 111–132. https://doi.org/10.1016/j.neubiorev.2020.03.001

De Keyser, K., De Letter, M., De Groote, E., Santens, P., Talsma, D., Botteldooren, D., & Bockstael, A. (2019). Systematic Audiological Assessment of Auditory Functioning in Patients With Parkinson's Disease. *Journal of speech, language, and hearing research :* JSLHR, 62(12), 4564–4577. https://doi.org/10.1044/2019_JSLHR-H-19-0097

De Keyser, K., Santens, P., Bockstael, A., Botteldooren, D., Talsma, D., De Vos, S., Van

Cauwenberghe, M., Verheugen, F., Corthals, P., & De Letter, M. (2016). The Relationship Between Speech Production and Speech Perception Deficits in Parkinson's Disease. Journal of Speech, Language and Hearing Research, 59, 915-931. http://dx.doi.org.proxy1.lib.uwo.ca/10.1044/2016_JSLHR-S-15-0197

De Pablo-Fernández, E., Lees, A. J., Holton, J. L., & Warner, T. T. (2019). Prognosis and neuropathologic correlation of clinical subtypes of parkinson disease. JAMA Neurology, 76(4), 470-479. https://doi.org/10.1001/jamaneurol.2018.4377

Dragojevic, M., Gasiorek, J., & Giles, H. (2016). Accommodative Strategies as Core of the Theory. In H. Giles (Ed.), Communication Accommodation Theory: Negotiating Personal Relationships and Social Identities across Contexts (pp. 36-59). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781316226537.003

Dromey, C., & Adams, S. (2000). Loudness perception and hypophonia in parkinson disease. *Journal of Medical Speech-Language Pathology,* 8(4), 255-259.

Duffy, J. R. (2019). *Motor speech disorders: Substrates, differential diagnosis, and management.* Elsevier Canada.

Dykstra, A. D., Adams, S. G., & Jog, M. (2012). The effect of background noise on the speech intensity of individuals with hypophonia associated with Parkinson's disease. *Journal of Medical Speech - Language Pathology*, *20*(3), 19+. https://link.gale.com/apps/doc/A327452230/AONE?u=lond95336&sid=bookmark-AONE&xid=d8707d34

Dykstra, A. D., Adams, S. G., & Jog, M. (2015). Examining the relationship between speech intensity and self-rated communicative effectiveness in individuals with parkinson's disease and hypophonia. *Journal of Communication Disorders*, 56, 103–112. https://doi.org/10.1016/j.jcomdis.2015.06.012

Ehgoetz Martens, K. A., Ellard, C. G., & Almeida, Q. J. (2013). Dopaminergic contributions to distance estimation in parkinson's disease: A sensory-perceptual deficit? *Neuropsychologia*, 51(8), 1426–1434. https://doi.org/10.1016/j.neuropsychologia.2013.04.015

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191. https://doi.org/10.3758/bf03193146

Faust-Socher, A., Kenett, Y. N., Cohen, O. S., Hassin-Baer, S., & Inzelberg, R. (2014). Enhanced creative thinking under dopaminergic therapy in parkinson disease. Annals of Neurology, 75(6), 935–942. https://doi.org/10.1002/ana.24181

Fox, C., Ebersbach, G., Ramig, L., & Sapir, S. (2012). LSVT LOUD and LSVT BIG: Behavioral Treatment Programs for Speech and Body Movement in Parkinson Disease. Parkinson's disease, 2012, 391946. https://doi.org/10.1155/2012/391946

Fox, C. & Ramig, L. (1997). Vocal sound pressure level and self-perception of speech and voice in men and women with idiopathic Parkinson disease. American Journal of Speech-Language Pathology, 6, 85–94. https://doi.org/10.1044/1058-0360.0602.85

Gaskin, J., Gomes, J., Darshan, S., & Krewski, D. (2017). Burden of neurological conditions in Canada. *Neurotoxicology*, *61*, 2–10. https://doi.org/10.1016/j.neuro.2016.05.001

Govil, N., Akinin, A., Ward, S., Snider, J., Plank, M., Cauwenberghs, G., & Poizner, H. (2013). The role of proprioceptive feedback in Parkinsonian resting tremor. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference, 2013, 4969–4972. https://doi.org/10.1109/EMBC.2013.6610663

Grimes, D., Gordon, J., Snelgrove, B., Lim-Carter, I., Fon, E., Martin, W., Wieler, M., Suchowersky, O., Rajput, A., Lafontaine, A. L., Stoessl, J., Moro, E., Schoffer, K., Miyasaki, J., Hobson, D., Mahmoudi, M., Fox, S., Postuma, R., Kumar, H., Jog, M., … Canadian Nourological Sciences Federation (2012). Canadian Guidelines on Parkinson's Disease. *The Canadian journal of neurological sciences. Le journal canadien des sciences neurologiques,* 39(4 Suppl 4), S1–S30. https://doi.org/10.1017/s031716710001516x

Gustafsson, J. K., Sodersten, M., Ternstrom, S., & Schalling, E. (2019). Voice Use in Daily Life Studied With a Portable Voice Accumulator in Individuals With Parkinson's Disease and Matched Healthy Controls. *Journal of Speech, Language, and Hearing Research*, 62(12), 4324+. http://doi.org.proxy1.lib.uwo.ca/10.1044/2019_JSLHR-19-00037

Halliday, G. M., & McCann, H. (2009). The progression of pathology in parkinson's disease. Annals of the New York Academy of Sciences, 1184(1), 188–195. https://doi.org/10.1111/j.1749-6632.2009.05118.x

Hammer, M. J., & Barlow, S. M. (2010). Laryngeal somatosensory deficits in Parkinson's disease: implications for speech respiratory and phonatory control. *Experimental brain research*, *201*(3), 401–409. https://doi.org/10.1007/s00221-009-2048-2

Healey, C. E., Jones, R., & Berky, R. (1997). Effects of perceived listeners on speakers' vocal intensity. *Journal of Voice*, 11(1), 67–73. https://doi.org/10.1016/s0892-1997(97)80025-2

Hegland, K. W., Troche, M., & Brandimore, A. (2019). Relationship Between Respiratory Sensory Perception, Speech, and Swallow in Parkinson's Disease. Movement disorders clinical practice, 6(3), 243–249. https://doi.org/10.1002/mdc3.12732

Ho, A. K., Bradshaw, J. L., Iansek, R., & Alfredson, R. (1999). Speech Volume Regulation in parkinson’s disease: Effects of implicit cues and explicit instructions. *Neuropsychologia*, 37(13), 1453–1460. https://doi.org/10.1016/s0028-3932(99)00067-6

Ho, A. K., Iansek, R., & Bradshaw, J. L. (1999). Regulation of parkinsonian speech volume: The effect of interlocuter distance. *Journal of Neurology, Neurosurgery & Psychiatry*, 67(2), 199–202. https://doi.org/10.1136/jnnp.67.2.199

Ho, A. K., Bradshaw, J. L., & Iansek, R. (2000). Volume perception in Parkinsonian Speech. *Movement Disorders*, 15(6), 1125–1131. https://doi.org/10.1002/1531-8257(200011)15:6<1125::aid-mds1010>3.0.co;2-r

Huang, X., Chen, X., Yan, N., Jones, J. A., Wang, E. Q., Chen, L., Guo, Z., Li, W., Liu, P., & Liu, H. (2016). The impact of parkinson’s disease on the cortical mechanisms that support auditory–motor integration for voice control. *Human Brain Mapping*, 37(12), 4248–4261. https://doi.org/10.1002/hbm.23306

Hunter, E. J., Cantor-Cutiva, L. C., van Leer, E., van Mersbergen, M., Nanjundeswaran, C. D., Bottalico, P., Sandage, M. J., & Whitling, S. (2020). Toward a Consensus Description of Vocal Effort, Vocal Load, Vocal Loading, and Vocal Fatigue.

Journal of Speech, Language, and Hearing Research, 63(2), 509+. http://dx.doi.org.proxy1.lib.uwo.ca/10.1044/2019_JSLHR-19-00057

Im, H., Adams, S., Abeyesekera, A., Pieterman, M., Gilmore, G., & Jog, M. (2018). Effect of levodopa on speech dysfluency in parkinson's disease. *Movement Disorders Clinical Practice*, 6(2), 150–154. https://doi.org/10.1002/mdc3.12714

Junqua, J.-C., Fincke, S., & Field, K. (1999). The lombard effect: A reflex to better communicate with others in noise. 1999 IEEE International Conference on Acoustics, Speech, and Signal Processing. Proceedings. ICASSP99 (Cat. No.99CH36258). https://doi.org/10.1109/icassp.1999.758343

Kiran, S., & Larson, C. R. (2001). Effect of duration of pitch-shifted feedback on vocal responses in patients with Parkinson's disease. *Journal of Speech, Language, and Hearing Research,* 44(5), 975+. https://link.gale.com/apps/doc/A80532483/AONE?u=lond95336&sid=bookmark-AONE&xid=2118fa5d

Knowles, T., Adams, S. G., Page, A., Cushnie-Sparrow, D., & Jog, M. (2020). A Comparison of Speech Amplification and Personal Communication Devices for Hypophonia. Journal of Speech, Language, and Hearing Research, 63(8), 2695+. https://doi.org/10.1044/2020_JSLHR-20-00085

Kwan, L. C., & Whitehill, T. L. (2011). Perception of speech by individuals with parkinson's disease: A Review. Parkinson's Disease, 2011, 1–11. https://doi.org/10.4061/2011/389767

Lane, H., Tranel, B., & Sisson, C. (1970). Regulation of voice communication by Sensory Dynamics. *The Journal of the Acoustical Society of America*, 47(2B), 618–624. https://doi.org/10.1121/1.1911937

Lee, A., & Gilbert, R. M. (2016). Epidemiology of parkinson disease. *Neurologic Clinics*, 34(4), 955–965. https://doi.org/10.1016/j.ncl.2016.06.012

Lieberman, P. (1963). Some effects of semantic and grammatical context on the production and perception of speech. *Language and Speech,* 6(3), 172–187. https://doi.org/10.1177/002383096300600306

Liu, H., Wang, E. Q., Metman, L. V., & Larson, C. R. (2012). Vocal Responses to Perturbations in Voice Auditory Feedback in Individuals with Parkinson's Disease. *PLoS ONE*, 7(3), e33629. https://link.gale.com/apps/doc/A477056663/AONE?u=lond95336&sid=bookmark-AONE&xid=c90e132e

Logemann, J. A., Fisher, H. B., Boshes, B., & Blonsky, E. R. (1978). Frequency and Cooccurrence of vocal tract dysfunctions in the speech of a large sample of parkinson patients. *Journal of Speech and Hearing Disorders*, 43(1), 47–57. https://doi.org/10.1044/jshd.4301.47

Lukhanina, E. P., Kapustina, M. T., Berezetskaya, N. M., & Karaban, I. N. (2009). Reduction of the postexcitatory cortical inhibition upon paired-click auditory stimulation in patients with Parkinson's disease. *Clinical Neurophysiology*, 120, 1852–1858. https://doi:10.1016/j.clinph.2009.07.040

Luo, J., Hage, S. R., & Moss, C. F. (2018). The Lombard effect: From acoustics to neural mechanisms. *Trends in Neurosciences*, 41(12), 938–949. https://doi.org/10.1016/j.tins.2018.07.011

Macleod, A. D., Taylor, K. S. M., & Counsell, C. E. (2014). Mortality in parkinson's disease: A systematic review and meta-analysis. Movement Disorders, 29(13), 1615-1622. https://doi.org/10.1002/mds.25898

Marks, L. E., & Florentine, M. (2011). Chapter 2 Measurement of Loudness, Part I: Methods, Problems, and Pitfalls. In Loudness (pp. 17–56). essay, Springer.

McCaig, C. M., Adams, S. G., Dykstra, A. D., & Jog, M. (2015). Effect of concurrent walking and interlocutor distance on conversational speech intensity and rate in Parkinson's disease. *Gait & posture*, 43, 132–136. https://doi.org/10.1016/j.gaitpost.2015.09.011

Miller, N., Allcock, L., Jones, D., Noble, E., Hildreth, A. J., & Burn, D. J. (2007). Prevalence and pattern of perceived intelligibility changes in Parkinson's disease. *Journal of Neurology, Neurosurgery and Psychiatry*, 78(11), 1188. https://doi.org/10.1136/jnnp.2006.110171

Pick, H. L., Jr, Siegel, G. M., Fox, P. W., Garber, S. R., & Kearney, J. K. (1989). Inhibiting the Lombard effect. *The Journal of the Acoustical Society of America*, 85(2), 894–900. https://doi.org/10.1121/1.397561

Pringsheim, T., Jette, N., Frolkis, A., & Steeves, T. D. L. (2014). The prevalence of Parkinson's disease: A systematic review and meta-analysis. *Movement Disorders*, *29*(13), 1583–1590. https://doi.org/10.1002/mds.25945

Ramig, L. O., Countryman, S., O'Brien, C., Hoehn, M., & Thompson, L. (1996). Intensive speech treatment for patients with parkinson's disease: Short- and long-term comparison of two techniques. *Neurology*, 47(6), 1496–1504. https://doi.org/10.1212/wnl.47.6.1496

Ramig, L. O., Fox, C., & Sapir, S. (2004). Parkinson's disease: Speech and voice disorders and their treatment with the Lee Silverman Voice treatment. Seminars in Speech and Language, 25(02), 169–180. https://doi.org/10.1055/s-2004-825653

Richardson, K. C., & Sussman, J. E. (2019). Intensity Resolution in Individuals With Parkinson's Disease: Sensory and Auditory Memory Limitations. Journal of Speech, Language, and Hearing Research, 62(9), 3564+. http://dx.doi.org.proxy1.lib.uwo.ca/10.1044/2019_JSLHR-H-18-0424

Rosen, K.M., Kent, R.D., Duffy, J.R. (2005). Task-based profile of vocal intensity decline in Parkinson's disease. Folia Phoniatrica et Logopaedica, 57(1), 28-37. https://doi.org/10.1159/000081959

Sapir, S., Ramig, L. O., & Fox, C. M. (2011). Intensive voice treatment in Parkinson's disease: Lee Silverman Voice Treatment. *Expert Review of Neurotherapeutics*, 11(6), 815+. http://dx.doi.org.proxy1.lib.uwo.ca/10.1586/ern.11.43

Schneider, J. S., Diamond, S. G., & Markham, C. H. (1986). Deficits in orofacial sensorimotor function in Parkinson's disease. *Annals of neurology*, *19*(3), 275–282. https://doi.org/10.1002/ana.410190309

Senthinathan, A., Adams, S., Page, A. D., & Jog, M. (2021). Speech Intensity Response to Altered Intensity Feedback in Individuals With Parkinson's Disease. *Journal of Speech, Language, and Hearing Research,* 64(6 SI), 2261+. http://dx.doi.org.proxy1.lib.uwo.ca/10.1044/2021_JSLHR-20-00278

Soleimani, M. A., Bastani, F., Negarandeh, R., & Greysen, R. (2016). Perceptions of people living with Parkinson's disease: a qualitative study in Iran. British journal of community nursing, 21(4), 188–195. https://doi.org/10.12968/bjcn.2016.21.4.188

Solomon, N. P., & Robin, D. A. (2005). Perceptions of effort during handgrip and tongue elevation in parkinson's disease. *Parkinsonism & Related Disorders,* 11(6), 353–361. https://doi.org/10.1016/j.parkreldis.2005.06.004

Therrien, A. S., Lyons, J., & Balasubramaniam, R. (2012). Sensory attenuation of self-produced feedback: The Lombard Effect Revisited. *PLoS ONE*, 7(11). https://doi.org/10.1371/journal.pone.0049370

Turnbull, R. (2019). Listener-oriented phonetic reduction and theory of mind. Language, Cognition and Neuroscience, 34(6), 747–768. https://doi.org/10.1080/23273798.2019.1579349

Winkworth, A. L., Davis, P. J., Ellis, E., & Adams, R. D. (1994). Variability and consistency in speech breathing during reading. *Journal of Speech, Language, and Hearing Research*, 37(3), 535–556. https://doi.org/10.1044/jshr.3703.535

Yuan, F., Guo, X., Wei, X., Xie, F., Zheng, J., Huang, Y., Huang, Z., Chang, Z., Li, H., Guo, Y., Chen, J., Guo, J., Tang, B., Deng, B., & Wang, Q. (2020). Lee Silverman Voice Treatment for dysarthria in patients with Parkinson's disease: a systematic review and meta-analysis. European Journal of Neurology, 27(10), 1957–1970. https://doi.org/10.1111/ene.14399

Appendix

Appendix A

Western University Health Science Research Ethics Board approval

Western Research

Date: 14 February 2023

To: Dr. Scott Adams

Project ID: 122213

Review Reference: 2023-122213-76180

Study Title: Loudness matching in individuals with Parkinson's disease and hypophonia

Application Type: HSREB Initial Application

Review Type: Delegated

Meeting Date / Full Board Reporting Date: 07/Mar/2023

Date Approval Issued: 14/Feb/2023 11:50

REB Approval Expiry Date: 14/Feb/2024

Dear Dr. Scott Adams

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study**.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
MOCA (1)	Other Data Collection Instruments	14/Jan/2023	1
Protocol for Loudness Matching in Parkinson Version Feb 11 2023	Protocol	11/Feb/2023	2
Phone Script for HC participants Feb 11 2023	Telephone Script	11/Feb/2023	2
LOI for HC participants Feb 11 2023	Written Consent/Assent	11/Feb/2023	2
LOI for PD participants Feb 11 2023	Written Consent/Assent	11/Feb/2023	2

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
References Loudness Matching in Parkinsons Version Feb 11 2023	References	11/Feb/2023	2

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Electronically signed by:

Patricia Sargeant, Ethics Officer [redacted] of Dr. Emma Duerden, HSREB Vice-Chair, 14/Feb/2023 11:50

Reason: I am approving this document

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations, See Electronic System Compliance Review)

Appendix B

Lawson Health Research Ethics Board Approval

LAWSON FINAL APPROVAL NOTICE

LAWSON APPROVAL NUMBER: R-23-053

PROJECT TITLE: Loudness Matching in Individuals with Parkinson?s Disease and Hypophonia

PRINCIPAL INVESTIGATOR: Dr. Scott Adams

LAWSON APPROVAL DATE: 15/02/2023

ReDA ID: 13128

Overall Study Status: Active

Please be advised that the above project was reviewed by Lawson Administration and the project was **approved**.

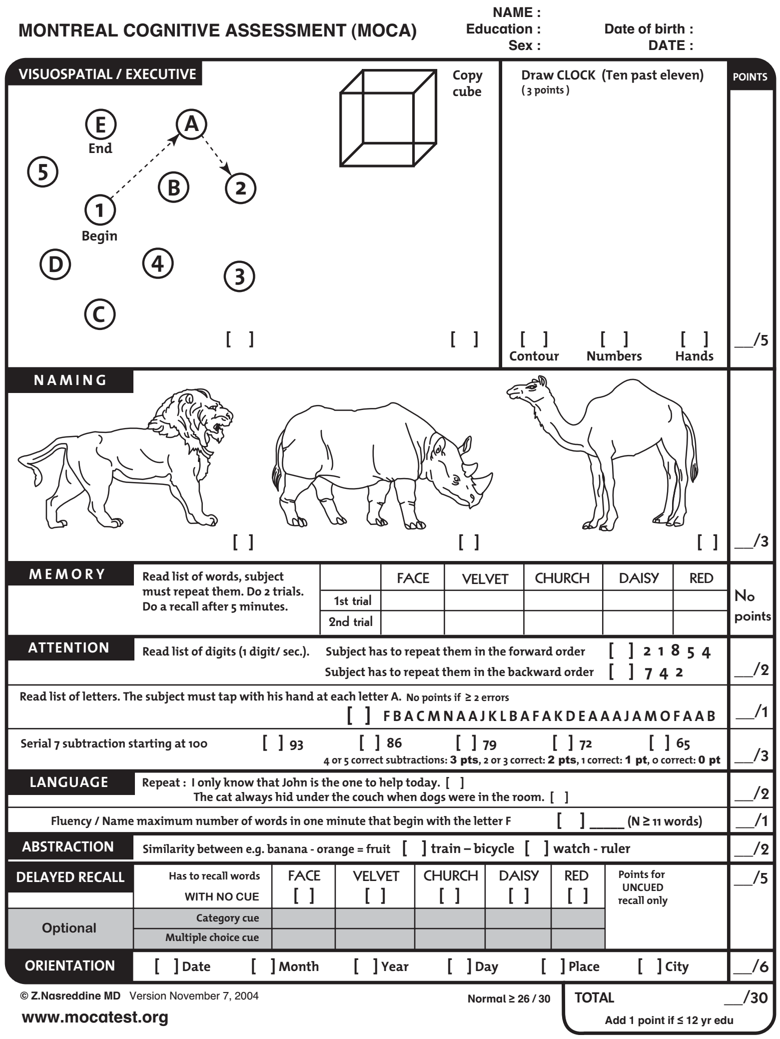
All research must follow applicable laws, regulations, policies, procedures and guidance, including hospital and Lawson policies, and Lawson Standard Operating Procedures.

Please provide your Lawson Approval Number (R# above) to the appropriate contact(s) in supporting departments (eg. Lab Services, Diagnostic Imaging, etc.) to inform them that your study is starting. The Lawson Approval Number must be provided each time services are requested.

Dr. David Hill
Scientific Director and Integrated V.P. Research
Lawson Health Research Institute

Appendix C

Montreal Cognitive Assessment



MONTREAL COGNITIVE ASSESSMENT (MOCA)

NAME :
Education :
Sex :
Date of birth :
DATE :

		POINTS
VISUOSPATIAL / EXECUTIVE — E End, A, 5, B, 2, 1 Begin, D, 4, 3, C [ ] — Copy cube [ ]	Draw CLOCK (Ten past eleven) (3 points) [ ] Contour [ ] Numbers [ ] Hands	___/5
NAMING [ ] [ ] [ ]		___/3

MEMORY — Read list of words, subject must repeat them. Do 2 trials. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED	No points
1st trial						
2nd trial						

ATTENTION	Read list of digits (1 digit/ sec.). Subject has to repeat them in the forward order [ ] 2 1 8 5 4 Subject has to repeat them in the backward order [ ] 7 4 2	___/2
	Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors [ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B	___/1
	Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65 4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**	___/3
LANGUAGE	Repeat : I only know that John is the one to help today. [ ] The cat always hid under the couch when dogs were in the room. [ ]	___/2
	Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words)	___/1
ABSTRACTION	Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler	___/2

DELAYED RECALL	Has to recall words WITH NO CUE	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only	___/5
Optional	Category cue							
	Multiple choice cue							

ORIENTATION	[ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City	___/6

© Z.Nasreddine MD Version November 7, 2004
www.mocatest.org

Normal ≥ 26 / 30 — **TOTAL** ___/30
Add 1 point if ≤ 12 yr edu