

Effect of Speaking Task on Intelligibility and Naturalness in Speakers with
Parkinson's Disease and Cerebellar Disease

Phillip Charles Weir-Mayta

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctorate of Philosophy

University of Washington
2014

Reading committee:

Kristie A. Spencer, Chair

Tanya Eadie

Kathryn Yorkston

Valerie E. Kelly

Program Authorized to Offer Degree:

Department of Speech and Hearing Sciences

© Copyright 2014

Phillip Charles Weir-Mayta

University of Washington

Abstract

Effect of Speaking Task on Intelligibility and Naturalness in Speakers with
Parkinson's Disease and Cerebellar Disease

Phillip C. Weir-Mayta

Chair of Dissertation Committee:

Kristie A. Spencer, Ph.D., CCC-SLP

Speech and Hearing Sciences

It is well established that individuals with Parkinson's disease (PD) have difficulty performing skilled movement when forced to rely on internal cues versus responses guided by external stimuli. This discrepancy has been attributed to the dysfunctional basal ganglia lacking an adequate, internally generated model causing persons with PD to become overly reliant on external cues to guide skilled movement. The extent to which speech production aligns with theories of internal versus external cuing is not well understood. The purpose of this study was to examine the effect of an internally versus externally cued speech task on the understandability and naturalness of speakers with PD and a clinical comparison group of speakers with cerebellar disease (CD) as perceived by 10 experienced speech-language pathologists. A direct comparison was made between sentences extracted from a covertly-recorded conversational sample (internally cued) and the reading of those same sentences by the speakers (externally cued). The listeners rated the speech samples using a visual analog scale for the perceptual dimensions of understandability and naturalness. Results suggest that experienced listeners perceived the speech of participants with PD as more natural and more understandable during the reading condition. The cerebellar group also demonstrated a difference between speaking conditions, but only for understandability. Thus, the percept of naturalness appeared to be sensitive to capturing the differences between speakers with Parkinson's disease and cerebellar disease.

TABLE OF CONTENTS

	Page
Introduction.....	1
Internal vs. External Cueing: Limb Motor	3
Theories of Internal vs. External Cuing Differences in PD.....	9
Internal vs. External Cueing: Speech.....	15
Other factors related to the examination of task-based speech changes in PD.....	27
Methods.....	31
Results.....	42
Discussion.....	50
Appendix A: Extraction Criteria.....	68
Appendix B: Software Programming.....	69
Appendix C: Directions.....	71
References.....	72

LIST OF TABLES

	Page
Table 1: Summary of results from Bunton & Keintz, (2008).....	22
Table 2: Summary of internal vs. external cueing speech studies.....	26
Table 3: Hypothesis Table.....	30
Table 4: Characteristics of participants with Parkinson’s Disease (PD) and Cerebellar Disease (CD)..	32
Table 5: Characteristics of experienced listeners (EL).....	34
Table 6: Sentence Intelligibility Test results and experienced listener ratings scores.....	36
Table 7: Number of perceptual judgments per group and speaking task.....	38
Table 8: Mean SPL in dBA per participant, per condition and overall means (SD) per group.....	41
Table 9: Mean (SD) timed length of sentence in seconds per speech sample.....	47
Table 10: Mean (SD) words per sentence and mean perceptual ratings per speaker and task.....	48
Table 11: Difference scores (covert conversation - reading) reflecting perceived change with the provision of written text/external cue across perceptual dimensions.....	49

LIST OF FIGURES

	Page
Figure 1: Visual analogue scale experienced listeners used for rating speech samples.....	40
Figure 2: Mean ratings of understandability by expert listeners across conversation and reading tasks for the group with cerebellar disease (CD) and Parkinson’s disease (PD).....	44
Figure 3: Paired t-test of mean perceptual ratings of experienced listeners for “Understandability” compared across speaking tasks for both groups. Error bars represent standard error.....	44
Figure 4: Mean ratings of naturalness by expert listeners across conversation and reading tasks for the group with cerebellar disease (CD) and Parkinson’s disease.....	46
Figure 5: Paired t-test of mean perceptual ratings of experienced listeners for “Naturalness” compared across speaking tasks for both groups. Error bars represent standard error.....	46

Acknowledgments

This dissertation could not have been completed without the help and support from professors, graduate students, technical support, funding, participants, and my family. It is my pleasure to acknowledge these individuals who have given me the guidance, help, and encouragement to make this endeavor a reality.

I would like to first and foremost express my deepest gratitude to my mentor, Dr. Kristie Spencer, for her constant guidance, personal attention, wisdom, patience, and support throughout my doctoral training program. Her direction and expectations encouraged perseverance, helping me to grow both academically and as a researcher, while preparing me for my future as a university professor.

Special thanks go to my advisory committee, Dr. Tanya Eadie, Dr. Kathryn Yorkston, and Dr. Valerie Kelly, for their contributions, guidance, and continued support. From them I have learned great lessons that I will carry with me throughout my academic career.

My special appreciation goes to graduate students I've worked with over the years in the Motor Speech and Cognitive Disorders Laboratory. Specifically, Erika Hutchison, Ashley France, Caitlin Sears, Sara Savaglio, Chris Woolcott, and Rebecca Porras; your time and efforts in assisting me are so greatly appreciated. Our friendships have definitely made my years at the University of Washington most memorable.

I also would like to take this opportunity to thank the technical support staff in the Speech and Hearing Sciences Department, especially Craig McDonald. Thank you for all your time in the lab making sure our programs ran correctly and our data was secure. I greatly appreciate all of your time and efforts.

I would like to thank the department of Speech and Hearing Sciences for their continued support of my education, the Training Grant in Speech and Hearing Sciences, as well as the University of Washington's Retirement Association's Fellowship in Aging. Without your financial support, my dream of becoming a university professor would have gone unmet.

It has been my pleasure to work with many participants and families from the community over the years. Thank you for taking the time to come into the lab and be a part of my research. Without which, none of this could have been possible.

I would also like to thank my family for always supporting and encouraging me to pursue my education. Additionally, I would like to dedicate this dissertation to the memory of my dad, Charles L. Weir, whose scholarly example and goals inspired me to pursue a doctorate degree and a career in academia.

Finally, I would like to thank my husband, Pete Mayta, who was always there to listen, support, and encouraged me throughout this entire process. He deserves an award for his many sacrifices along the way. Thank you Pete for being my husband and my best friend!

Introduction

It is well established that individuals with Parkinson's disease (PD) have difficulty performing skilled movement when forced to rely on internal cues versus responses guided by external stimuli (Gowen & Miall, 2007; Ketcham et al., 2003; Sawamoto et al., 2002; Morris, 2000; Van Donkelaar et al., 2000). Most attribute this difficulty to dopaminergic deficits affecting the basal ganglia and fronto-striatal networks, areas involved in the preparation of internally generated movements (Briard et al., 1999; Cunnington et al., 1995; Lewis et al., 2007; Morris et al., 2000; Schenk et al., 2003). As a result, individuals with PD become overly reliant on external cues (i.e., visual, auditory) to guide skilled movement (Romero et al., 2003). Converging evidence suggests marked improvement in performance with external cues for behaviors such as gait (Luessi, Mueller, Breimhorst, & Vogt, 2012; Mak, Yu, & Hui-Chan, 2013), writing (Oliverira et al., 1997; Teulings et al., 1997), and driving (Sally et al., 2011; Stolwyk et al., 2005). While the effect of internal versus external cues on speech intelligibility has been investigated for a small number of speakers, findings have been inconsistent. Some investigators report that individuals with PD speak more intelligibly during speech tasks that provide an external model (e.g., reading, repeating) compared to spontaneous speech tasks (Kempler & Van Lancker, 2002; Sidtis et al., 2012). However, others suggest that intelligibility is negligibly changed with an external auditory or visual cue, and thus similar in monologue and reading conditions (Bunton and Keintz, 2008; Tjaden and Wilding, 2011). These discrepancies are likely due to differences in methodology and analyses making it difficult to draw conclusions about the presence and nature of task-based speech differences.

While intelligibility is often affected in speakers with PD, it is perhaps not the most salient indicator of impaired communication in this population. It is not unusual for speakers with PD to have relatively preserved intelligibility, but disrupted prosody (Duffy, 2013). Yet, to date, studies of speaking task differences in PD have focused exclusively on speech intelligibility to the neglect of speech naturalness. Speech naturalness relates to a speaker's prosody which encompasses speech rate, rhythm, intonation, stress patterns and loudness (Yorkston et al., 1999)– features that are often dramatically and pervasively affected in speakers with dysarthria from PD. Thus, relying solely on intelligibility may not provide the most sensitive or complete indicator of task-based speech changes.

The purpose of this proposal is to examine the effect of an internally versus externally cued speech task on understandability and naturalness in speakers with hypokinetic dysarthria from PD. Specifically, this study will explore differences in perceived understandability and naturalness across two tasks, reading and a conversational speech sample recorded covertly, while content is held constant across the two elicitation conditions. It is predicted that understandability and naturalness will be perceived more favorably in a speech elicitation condition that provides an external model (i.e., reading) versus one that relies on an internal model (i.e., covert-conversation). If there are indeed pronounced differences in performance between speech elicitation tasks for individuals with PD, then a better understanding of this phenomenon should inform both theory and clinical practice.

To establish motivation for this study, a summary will first be provided of clinically-focused research on internal versus external cueing in limb movements of individuals with PD. Next, theories will be reviewed that address the discrepancy in performance between internally

and externally cued tasks. Then, a summary of the literature detailing the influence of external and internal cueing on speech intelligibility will be provided. A brief background also will be given on the importance of including naturalness as an outcome measure, and including a clinical comparison group (i.e., speakers with ataxic dysarthria).

Internal vs. External Cueing: Limb Motor Control

External cues have been shown effective in triggering sequential movements and improving movement characteristics in individuals with PD (Burleigh-Jacobs et al., 1997; Freeman et al., 1993; Lehman et al., 2005; Majsak et al., 1998; Mak et al. 2004; McIntosh et al., 1995; Morris et al., 1996; Thaut et al., 1996). Considerable research has demonstrated improvements in gait, upper extremity movements, and complex behaviors such as driving when visual and/or auditory cues are provided (Bagley et al, 1991; Bryant et al., 2010; Enzensberger & Fischer, 1996; Forssberg et al, 1984; Freedland et al., 2002; Howe et al, 2003; Jahanshahi et al., 1995; Lehman et al., 2005; Lim et al., 2005; Lings & Dupont, 1992; Madeley et al., 1990; McCoy et al, 2002; Nieuwboer et al., 2009; Norwak et al., 2005; Oliverira et al., 1997; Ringebach et al., 2011; Scally et al., 2005, 2011; Swinnen et al., 2002; Teulings et al., 2002; Zesiewics et al., 2002).

Effect of external cues on gait

Visual cues have been shown by numerous studies to be a powerful means of improving gait in PD (Rubinstein et al., 2002). These external cues include strategies such as markings on the floor and laser projections. Floor markings are typically placed perpendicular to the gait path, spaced about one step length apart, and can be used to improve spatial and temporal parameters of walking. In a series of experiments, Morris and colleagues (1996) examined the

use of visual floor markings in 16 participants with mild-to-severe PD and 16 age-matched controls. Participants were asked to walk 12 meters while a computerized clinical stride analyzer measured temporal and spatial parameters of footstep patterns. The study revealed that visual cue training was effective for enhancing stride length regulation. This training effect transferred to walking without visual cues and led to normalization of stride length, velocity, cadence, and double support duration for at least two hours post training. These findings were consistent with earlier studies (Bagley et al, 1991; Forssberg et al, 1984; Morris et al., 1994) which reported immediate performance effects with floor markers. Although many studies support the utilization of floor markings, some investigators have reported negative findings in visual cue use for gait. For instance, Azulay et al. (1996) found no sizeable changes in stride length and velocity with visual cues (transverse white stripes placed on the floor) in 13 individuals with PD. Even so, the vast majority of research supports the use on floor markings to improve gait in persons with PD.

Lasers have also been used as another type of visual cue that results in improved walking performance in individuals with PD. Placement of the laser requires the use of a Subject Mounted Light Device that allows for laser attachment to the participant's chest via a specially designed vest. The device projects two laser lines onto the floor in front of the participant. The participant is then instructed to "step up to the line as you walk along the runway." Using this device, Lewis et al. (2000) examined stride length and gait velocity in 14 participants with PD (Hoehn & Yahr Stages 1-4, M = 2.8) and 14 age-matched controls. Participants were asked to walk up and down a 10m runway 10 times. Three-dimensional kinematic and kinetic gait analyses were conducted using motion analysis equipment and a full body marker set. Results

demonstrated that the use of laser generated lines were able to improve spatiotemporal gait patterns. Given these outcomes, the authors speculated that improvements in gait pattern with the use of visual cues may arise through the patients' ability to utilize visual feedback to regulate movement amplitude, reducing their reliance on kinesthetic feedback. Comparable finds, along with a reduction in freezing of gait, was demonstrated in six individuals with PD (Van Gerpen et al., 2012).

Auditory cues are another form of external cueing shown to enhance gait (Cubo et al, 2004; Eni, G., 1988; Enzensberger & Fischer, 1996; Freedland et al., 2002; Freeman et al., 1993; Howe et al, 2003; Jahanshahi et al., 1995; Lehman et al., 2005; Lim et al., 2005; McCoy et al, 2002; Thaut et al., 1996). Auditory cues can be verbal instructions (e.g., "take big steps") or rhythmic auditory stimulation which includes use of a metronome or a steady beat from a musical listening device. Lehman et al. (2005) examined the use of verbal instructional cues to improve gait in five participants with PD (Hoehn & Yahr Stage 2-2.5). Participants were asked to walk 1800 feet while being instructed to "take long steps". Results revealed a significant increase in step length and velocity with a significant decrease in cadence. Similar improvements to step length and velocity with the use of verbal instructions have also been shown by Behrman et al. (1998) and McCoy et al. (2002).

A study by Freedland and colleagues (2002) serves as an example of the benefit of rhythmic auditory stimulation on gait. In their investigation, metronome cueing was implemented to examine the gait of 16 individuals with PD. Participants were asked to walk along a 4.6 meter walkway with sensors that allowed for recording of gait parameters. Results revealed significant improvements in cadence, cycle time, double support, step length, mean

normalized velocity, and step-extremity ratio. Similar benefits of rhythmic auditory stimulation have been reported in a number of studies (Enzensberger & Fischer, 1996; Freeman et al., 1993; Ito et al., 2000; Jahanshahi et al., 1995; McIntosh et al., 1995; Rochester et al., 2005; Taut et al., 1996; Thaut et al., 1996). Although rhythmic auditory stimulation is advocated as a walking aid in several studies, auditory metronome pacing slowed walking and was not a beneficial intervention for freezing in a study by Cubo et al. (2004). Further, Lim et al. (2005) in a systematic review of rhythmic auditory stimulation cautions that although strong evidence favors auditory rhythmic cuing in the treatment of gait, the impact of reported effects measured in a laboratory setting are difficult to generalize to home and other everyday environments. As such, additional research regarding the generalization of these external cues is warranted.

Effect of external cues on upper extremity movement

External cues have also been shown to be effective in improving characteristics of upper extremity movements (Bryant et al., 2010; Freeman et al., 1993; Majsak et al., 1998; Nieuwboer et al., 2009; Norwak et al., 2005; Oliverira et al., 2009; Ringebach et al., 2011; Scally et al., 2011; Swinnen et al., 2002). Similar to gait, visual cues can enhance arm reaching movements and writing as well. For example, Majsak et al. (1998) used a moving ball to examine accuracy and velocity of reaching movements in six individuals with PD (Hoehn & Yahr Stage 3) and six age-matched controls. Using two-dimensional kinematic analysis, the researchers demonstrated that individuals with PD, in the presence of a visuotemporal stimulus, were able to generate reaching velocities that exceeded their self-regulated maximal speed and that matched the speed of healthy subjects. Furthermore, participants with PD increased their reaching speed

without a notable compromise in movement accuracy. The authors suggested that the moving target provided individuals with PD a means of organizing the timing and speed of their movements, compensating for their loss of internal cueing mechanisms. Increased reach velocity and decreased movement time using a visual cue has also been demonstrated in other studies of arm movements in PD (Curra et al., 1997; Georgiou et al., 1993; Kelly et al., 2002).

Like other motor skills, writing becomes increasingly difficult for individuals with PD. Over time, writing becomes abnormally small and difficult to read, a condition referred to as micrographia. Research examining the use of visual cues, such as dots, parallel lines, and grids, has demonstrated improvements in writing amplitude, velocity, and consistency of spatial trajectories. For instance, Bryant et al. (2010) examined the use of parallel and grid lines to improve letter size in 11 participants with mild-to-moderate PD compared to free writing. Similar to previous studies (Oliverira et al., 1997; Teulings et al., 2002), the provision of visual cues helped to specify the desired amplitude of movement, improving overall letter size and accuracy. Moreover, Nieuwboer et al. (2009) reported that in addition to improvements in movement amplitude, visual cues also decreased the number of upper limb freezing episodes during writing in 20 participants with PD (Hoehn & Yahr Stages 2-4).

In addition to visual cues, upper extremity movements have also been shown to benefit from the use of auditory cueing. In 2002, Swinnen and colleagues compared improvement following practice of a bimanual figure drawing in 13 individuals with mild-to-severe PD and healthy age-matched controls. At initiation of practice, the typical symptoms associated with PD became evident, such as bradykinesia and hypometria. Following two practice sessions, during which a metronome was used to pace performance, participants with PD showed

marked improvements in the speed of execution, the consistency of spatial trajectories, and synchronization of limbs, though performance levels did not quite reach those obtained by the elderly controls. In a later experiment, Ringebach and colleagues (2011) investigated the performance of unimanual and bimanual upper limb line drawing using auditory (verbal and tonal) and visual cues in 15 participants with PD (UPDRS range 9-45), 15 elderly individuals, and 15 young adults. Comparisons between the groups indicated that participants with PD actually showed greater relative improvements in bimanual motor performance following external movement cues. The authors point out that improved upper extremity function, especially in tasks requiring a timing component, suggests cue-based interventions may be useful in improving upper extremity motor function in people with PD. Even though the benefit of auditory and visual cues to upper extremity movements has been well documented, investigations are needed examining the long term maintenance of improved function, including improvements noted in micrographia.

Effect of external cues on driving

The impact of impaired internal cueing mechanisms can also be seen in the driving performance of individuals with PD, an issue that can have critical implications for safety (Rizzo et al., 2010; Klimkeit et al., 2009). Findings from simulator studies have consistently demonstrated increased reaction times, greater inaccuracy of steering, a higher number of missed red lights, and increased collisions (Lings & Dupont, 1992; Madeley et al., 1990; Scally et al., 2005, 2011; Zesiewics et al., 2002). With progression of the disease, persons with PD become increasingly reliant on external cues to regulate driving behavior (Stolwyk et al., 2005). As such, Scally and colleagues (2011) investigated the impact of external cue validity on

simulated driving performance in 19 participants with mild-to-moderate PD and 19 healthy age-matched controls. Braking points, and distance between deceleration point and braking point, were analyzed for red traffic signals preceded either by *Valid Cues* (road sign with flashing green or red light congruent with the upcoming traffic signal), *Invalid Cues* (flashing green or red light incongruent with the upcoming traffic signal), and *No Cues* (no flashing light). Participants with PD were found to brake significantly later than controls under *Invalid* and *No-Cue* conditions, yet braked comparably to controls under *Valid Cue* conditions. This pattern of findings reinforces the benefits of valid external cues on motor performance in PD (Azulay et al., 2006; Baker et al., 2007, 2008; Cunnington et al., 1999; Ledger et al., 2008; Lim et al., 2005; Nieuwboer et al., 2007; Scally et al., 2005; Van Wegen et al., 2006).

In summary, external cues have been shown effective in enhancing movement characteristics of gait, writing, and driving in individuals with PD. While limb movement studies are not a direct parallel to the speech tasks of interest, they do provide evidence that external cues improve performance of skilled movements. Like with limb movements, the basal ganglia are also involved with the selection, scaling, and guidance of speech movements. With these physiological commonalities between the two systems, examination of the similar manifestations of deficits and similar benefit of external cueing to speech movement is receiving growing attention in the speech literature.

Theories of Internal vs. External Cueing Differences in PD

Neuroanatomical Basis for Internal Cueing

The basal ganglia as a whole have been implicated in a wide variety of motor functions, including the planning, programming, initiation, and execution of movements (Abbruzzese &

Berardelli, 2003; DeLong, 2000; Houk & Wise, 1995; Martin et al., 1994). However, unlike most other components of the motor system, they do not have direct connections with the spinal cord. Rather, the basal ganglia receive afferent fibers from the cerebral cortex via the striatum and send efferent fibers exiting the basal ganglia through the globus pallidus and substantia nigra to the brain stem and thalamus and, via the thalamus, back to the frontal cortex (Turner, 2010). The basal ganglia strongly influence motor control through four different functional circuits or “loops” that include the thalamus and the cortex (DeLong, 2000; Shumway-Cook & Woollacott, 2012, Turner, 2010). These circuitries comprise the skeleto-motor circuit (including the premotor cortex, supplementary motor cortex, primary motor cortex, putamen, globus pallidus, and ventrolateral thalamus), the oculomotor circuit, the prefrontal circuits, and the limbic circuit (Alexander et al., 1995; Turner, 2010). Although each circuit contributes to movement, it is the skeleto-motor circuit that contributes to both the preparation and execution of skilled motor acts.

Movement can be initiated in response to external stimuli and cues or through internally driven, self-initiated processes. Different areas of the brain are thought to be preferentially involved in each form of movement. The basal ganglia are thought to be more important for internally cued movements (Jueptner & Weiller, 1998; Mushiake & Strick, 1995; Van Donkelaar et al., 1999, 2000). The major output pathways of the BG originate in the globus pallidus and travel through the thalamus for relay back to the Supplementary Motor Area (SMA) and prefrontal motor areas (Duffy, 2013). The SMA also sends projections into the BG (Saint-Cyr et al., 1995), the putamen (Ferrandez et al., 2003), and subthalamic nucleus (Paradiso et al., 2003). These fibers transmit information that is important to movement initiation and the

inhibition of unwanted movements. Additionally, these connections allow for involvement of the SMA in the internal cueing process (Berardelli et al., 2001; Cunnington et al., 1996; Curra et al., 1997; Georgiou et al., 1994; Goldberg, 1985; Cuye et al., 1998; Inzelberg et al., 2001; Morris & Passingham, 1997; Robertson & Flowers, 1990). Evidence of SMA involvement in the internal cueing process can be inferred from movement-related potentials which are associated with the preparation and execution of voluntary or internally determined movements (Cunnington et al., 1995). Cunnington and colleagues (1995) investigated movement-related potentials associated with sequential movements under various cueing conditions in individuals with PD and age-matched controls. In controls, movement-related potentials revealed involvement of the SMA in movements which can be internally determined (non-cued and externally cued, predictable movements, but not unpredictable movements). In PD, however, the SMA was only involved in movements which must be internally determined (non-cued movements, but not externally cued movements). Therefore, impaired internal control mechanisms, operating via the SMA, are bypassed when external cues are given (Cunnington et al., 1995). As a result, patients with PD are more reliant on external cues and are unable to use predictive models to internally guide movement. Thus, with disrupted BG output impacting the SMA, individuals with PD have a difficult time switching to an internal mode of control to improve movement performance (Cunnington et al., 1995).

An example of defective internal cueing can be seen in the gait of individuals with PD. Morris and colleagues (1996) hypothesized that the BG are involved in providing phasic, internal cues to the SMA, which is responsible for activating and deactivating each sub-movement within a movement sequence. When internal rhythmic cues are not supplied

properly due to basal ganglia/SMA disruption, movements lose their smoothness. As a result, internal walking rhythm may exhibit freezing and festination of movement, a primary gait deficiency in PD (Giladi et al., 1992; 2001). In speech motor control, the SMA plays a role in sequencing and self-initiation of planned speech acts (Bohland et al., 2009). As a result of basal ganglia/SMA impairment, the preparatory aspects of speech production such as speech motor planning, programming, and motor program maintenance for movement sequences may become disrupted (Ho et al., 1999; Iansek et al., 1995; Spencer, 2007).

Internal Modeling of Speech Production and the Role of Cueing

The preparatory aspects of a motor act, its initiation, and execution are a dynamic process. Before preparation can begin, the motor cortex must first receive information from the periphery regarding the current situation and the body's position within the environment. The basal ganglia are able to access and gather this incoming somatosensory, visual, and auditory information via numerous afferent and efferent connections discussed previously (Brooks, 1986; Evarts & Wise, 1984; McGeer & McGeer, 1987; Nauta & Domesick, 1984). The BG then works closely with other brain regions, including the cerebellum, SMA, motor cortex, and the frontolimbic system, to plan and program movement sequences. These preparatory processes are guided by numerous internal triggers throughout the basal ganglia circuitry. Following preparation, movements are released through competition between the direct and indirect pathways, mediated by the basal ganglia (Graybiel, 2000; Turner, 2010). This battle allows for the "filtering" out of unwanted motor patterns, allowing for execution of desired motor programs through the motor system. During movement execution, the nervous system must constantly receive sensory information from the outside world and relay it to the basal ganglia.

The basal ganglia can make any adjustments needed, ensuring that the movements are fast, precise, smooth, and coordinated (Wichmann & DeLong, 1999). Following completion of the movement, the basal ganglia, along with the cerebellum, can evaluate the accuracy of the movement outcome to determine how well the motor goal was achieved and update any motor plans that were in error (Turner, 2010). Impairments to this preparatory process, such as the case in individuals with PD, reduces and/or delays the proficiency at which internal triggers are able to guide movement, explaining some of the movement dysfunctions seen in this population (Cunnington et al., 1995).

The basal ganglia's involvement in the speaking process parallels many of the same processes seen for limb motor control. Yet here, speakers must plan the phonological content of their utterances before their release as speech motor acts (Bohland et al., 2009). Planning involves the translation of an abstract, internal linguistic-phonologic representation into a code that can be interpreted by the motor system (Duffy, 2013; Van Der Merwe, 1997). Once the phonologic representation of a verbal message is in place, a program to guide movements for speech execution can be organized and activated. A program supplies certain movement parameters to specific muscles or muscle groups regarding muscle tone, direction, force, range, and rate (Duffy, 2013; Van Der Merwe, 1997). The neural areas involved in motor programming of speech include the basal ganglia, cerebellum, SMA, motor cortex, and the frontolimbic system (Van Der Merwe, 1997). Similar to the limb motor system, the basal ganglia uses numerous afferent and efferent connections to gather somatosensory and auditory inputs that help guide the selection of muscle commands that will match predicted sensory consequences of speech acts (Lidsky et al., 1985; Bohland et al., 2009). Following speech execution, the

resulting somatosensory and auditory signals can be fed back into the system and compared to predictions, allowing for updating of the program error for subsequent trials (Bohland et al., 2009). When this internal mapping process is disrupted due to basal ganglia disease such as Parkinsonism, the selection and guiding of speech muscle movements become incomplete. Thus, hypokinetic speech gives the impression that the underlying speech movements are there, but have been attenuated in range or amplitude and restricted in their flexibility and speed (Duffy, 2013).

The Role of Attention in Speech Intelligibility

Externally cued tasks, by their very nature, often heighten a person's awareness and attention to the task itself. As such, could differences between internally and externally cued tasks be driven simply by attention to task? External factors such as use of speech materials, physical setting, and/or motivation could increase speaker's attention to their speech productions, enhancing performance (Goberman & Elmer, 2005; Hustad & Weismer, 2007; Kent et al., 1989). During a speech evaluation, clinicians implement various testing materials and tasks designed to elicit a speech sample from the patient. The sample is then used to ascertain the speech capabilities of the speaker. When using these materials, it is likely that the clinician has increased the speaker's attention to the task of speech production and thus affected his or her behavior (Kent et al., 1989). Speakers can improve intelligibility of their speech through attention to effort or selective enhancement of particular aspects of the signal. As a result, speech production is clearer. Similar performance effects for speakers with PD in clinical and laboratory settings have been reported (Keintz et al., 2007; Neelly, 1956; Sarno, 1968; Weismer, 1984). In these studies, improvement in speech performance was thought to be due to the

presence of simple visual cues (e.g., facial expressions) that focus a speaker's attention on the target behavior. Thus, it might be that increased attention alone is successful in normalizing many of the deficits of performance associated with PD, including speech.

Internal vs. External Cueing: Speech

Although our understanding of the effects of internal versus external cueing stems primarily from the limb motor literature, evidence is emerging regarding speech production. For instance, Ho et al. (1999) examined the regulation of speech volume in hypophonic subjects with PD and age-gender matched controls. Control participants were able to adjust their speaking volume automatically when competing against increasing levels of background noise. When the background noise was decreased, the controls automatically decreased their speaking volume appropriately. The authors attributed this finding to the ability of healthy individuals to rely on internal cueing mechanisms that allows them to adjust their speaking volume in order to match the needs within the speaking environment. Individuals with PD, on the other hand, were less able to adjust their volume with changes in background noise. The authors suggested that the dysfunctional internal cueing mechanisms of the basal ganglia were not able to recognize and prepare the appropriate motor commands to increase or decrease volume as needed to compensate for changes in environment. When an external cue was provided instructing the hypophonic speakers to focus on their speaking volume, performance normalized to that of controls. Thus, by providing an external cue to compensate for faulty internal cueing triggers of the basal ganglia, participants with PD were able to speak with normal volume.

The ability of individuals with PD to regulate their volume through the use external cues was investigated and developed into a successful treatment protocol referred to as the Lee Silverman Voice Treatment (LSVT) (Ramig et al., 1995). LSVT teaches hypophonic speakers to disregard their defective internal cues and instead “recalibrate” their volume using external cues to “think loud”. Following treatment, individuals are better able to regulate their speech volume comparable to healthy speakers (Ramig et al., 2001) and maintain this performance at 6 months post (Fox et al., 2002; Ramig et al., 2001). These findings speak to the benefit of external cues to improve speech production in individuals with impaired basal ganglia function.

Apart from improvements in speech volume regulation, benefits of external, auditory cues have been shown in a pacing study to have an impact on speech intelligibility as well. Thaut et al. (2001) examined the effect of rhythmic auditory cues on speech intelligibility in PD. Participants with hypokinetic dysarthria provided speech samples under three different rate conditions (habitual speech rate, 80% of habitual rate, and 60% of habitual rate) across two different rhythm pacing conditions (metered versus patterned rhythm). Overall mean intelligibility rates improved significantly from 68.9% to 82.5%. When considering improvements in intelligibility relative to severity level of participants, speakers with severe impairment significantly improved from 44.2% to 85.1%, while speakers in the moderately affected group made a statistically insignificant improvement from 70.1% to 77.8%. Intelligibility rates also showed no improvement for the mildly impaired group, which was expected given their high baseline levels of intelligibility. These results suggested that rhythmic speech cueing significantly improves speech intelligibility in individuals with severe hypokinetic dysarthria from PD. The authors speculated that the rhythmic auditory cues acted as pace-

keepers for the impaired internal model. This finding parallels the use of rhythmic auditory cues to improve festinating of gait in individuals with PD (Lim et al., 2005) discussed previously.

Studies have also investigated the effects of internal versus external cues via speech elicitation conditions on the connected speech of individuals with PD (see Table 2 for a summary). In an early study by Canter and Van Lancker (1985), the researchers examined the speech of a 45 year old male who had become dysarthric following bilateral thalamic surgery for relief of PD symptoms, and that of a healthy control. The speech deficits of the speaker with PD were more apparent during connected speech, and characterized as rapid with mild-to-moderately impaired articulation. To measure intelligibility, the participants were asked to read the "Rainbow Passage" and to describe their job to elicit a speech monologue. From each of the two recorded productions, 20 phrases (4-7 words in length) were selected per task per participant. In each phrase, two individual words or short phrases were selected as "target" items, resulting in 40 key items per task, per group to be used for intelligibility scoring. A total of 58 college students were selected to listen to the recording and write down each item presented. 32 listeners heard items from the reading passage randomized between participants, while 26 of the listeners heard randomized items from the monologue task. The speaker's intelligibility score was derived from the mean percentage of target items identified correctly of the total 40 items in each sample. Overall intelligibility for the control participant was 95% for oral reading and 97.5% for monologue. For the individual with PD, intelligibility scores were 31% for reading and 23% for monologue; his speech was notably less intelligible for the monologue production versus reading. Thus, here the provision of an external model (reading) seems to have improved speech production over that of monologue speech. Yet these

results should be considered with caution as they are based on only one individual with PD. Additionally, although the reading passage items were randomized, listeners of the passage may have benefited from repeat exposure to items. Thus, the possibility of a listener learning effect exists.

Variability of speech performance was later examined by Kempler et al. (2002) by evaluating intelligibility across five speech tasks, including monologue and reading. The speaker was diagnosed with PD 18 years prior and was stage 2 on the Hoehn and Yahr (1967) scale, with moderate hypokinetic dysarthria. Through a conversation about his early life, a spontaneous speech sample was obtained. One examiner remained in the room while the other completed a transcription of 30 utterances which were later presented back to the participant for reading, repeating, and singing stimuli. The utterances were heterogeneous in theme and free of repetitions and proper names. The listening task used a cloze format with 100 blanks for the target words. Sixty-four listeners participated and listened to tapes in a sound field via a speaker set at a "comfortable" loudness level. Results demonstrated significantly better intelligibility (78%) for the reading task versus the monologue task (29%). The authors attributed the low intelligibility of the monologue to the inability of the basal ganglia to provide an accurate internally generated model. The reading and repeating tasks putatively provided enough external support to reduce the demands on the basal ganglia for planning, initiating, and/or monitoring of speech gestures. Like Canter and Van Lancker (1985), this study also considered only one individual with PD which may not be representative of the population as a whole. Additionally, the listening task conditions were not consistent across listeners as they were allowed to adjust the volume as need to a "comfortable" level. A case study of a severely

dysfluent man with parkinsonian syndrome found similar results (Van Lancker Sidtis et al., 2012). That is, on all fluency measures, spontaneous speech was more impaired than repetition, reading, sentence repetition or singing.

Task-based changes to connected speech were also examined by Sidtis and colleagues (2012) for six individuals with PD and five individuals with PD plus Deep Brain Stimulation (DBS). All speakers presented with mild hypokinetic dysarthria. The content of speech samples in two production modes (monologue and repetition) was matched by having subjects repeat their own utterances previously obtained during spontaneously produced monologue speech. 170 total utterances were extracted and used in a cloze procedure that included 426 target words. Listeners (N=30) were required to listen to each utterance once over headphones, adjusted to a comfortable listening level, and fill in the blanks with the word or words they heard. Following each utterance was a five point rating scale where each listener was asked to rate the difficulty in understandability of the utterance just presented. Results suggested that overall repetition trended towards being more intelligible than monologue for PD, PD-DBS (ON), and PD-DBS (OFF) conditions. The authors attributed these results to theories of motor behavior that contrast external with internal models. In repeated speech, a phrase produced by another speaker (repetition) provides an external model, reducing the burden of effort for the basal ganglia. Limitations of this study, including small sample size, all mildly dysarthric, younger participants, and inconsistent listening volume levels, warrant caution when interpreting findings.

While studies reviewed thus far have paralleled findings from the limb motor control literature, other researchers have found questionable benefit to speech from the provision of

external cues. Bunton and Keintz (2008) calculated speech intelligibility across a number of different speech tasks in single- and dual-task conditions for four speakers with hypokinetic dysarthria from PD (all Hoehn-Yahr stage 3) and four age-matched controls. In speech-only (single-task) and speech plus motor (dual-task) conditions, participants provided three types of speech samples: (1) reading 71 monosyllabic words from the Kent et al. (1989) intelligibility test, (2) reading 60 low predictability sentences from the Hearing in Noise Test (HINT, Kalikow et al., 1977), and (3) producing a monologue about a recent vacation. In the dual task condition, the secondary motor task involved assembling nuts and bolts. To avoid benefit from visual guidance, the participants performed the motor task while keeping their hand in their lap under a black cloak. In addition to the speech tasks above, a two-to-three minute spontaneous speech sample was recorded unbeknownst to each speaker. The premise for eliciting the monologue in the single- and dual-task conditions, and comparing intelligibility to that of the spontaneous speech sample, was to see if inclusion of a secondary motor task while speaking would elicit a functional speech sample comparable to everyday speech. To this end, the only difference between the spontaneous speech sample and monologue was that speakers had knowledge of the expectations for the monologue task (speech intelligibility) and were aware of being recorded. Following collection, the speech samples were digitized and presented over a speaker with consistent volume to 96 listeners age 18-50. Listeners were asked to write down what they heard as accurately as possible. Intelligibility was determined by how many words were identified correctly and dividing by the total number of possible words for a given speech task. Scores were then averaged across listeners.

In the **single- task condition** (speaking only), intelligibility for control participants was similar for the three overt speech tasks (reading single words = 99.09%, reading sentences = 98.09%, and monologue = 97.45%). The difference between scores from the overt monologue (97.45%) and the covert spontaneous speech sample (98.4%) was not statistically significant. Participants with PD also had similar intelligibility scores across the overt speech tasks (reading of single words = 90.75%, reading sentences = 90.2%, and monologue = 87.5%). In contrast to control participants, the difference in intelligibility scores between the overt monologue (87.5%) and the covert spontaneous sample (74.25%) in participants with PD was statistically significant.

Results for participants with PD in the single-task condition differed from Kempler and Van Lancker (2002), who found significant differences in speech intelligibility for sentence reading (78%) as compared to monologue production (29%). Kempler and Van Lancker's findings are consistent with previous studies where intelligibility in single-word reading, as well as sentence-reading tasks, is preserved; while intelligibility is degraded in monologue (Canter & Van Lancker, 1985; Tjaden & Wilding, 2004). Bunton and Keintz (2008) speculated that in previous studies, changes in intelligibility may have been related to setting and communication partner. The authors hypothesized that intelligibility was better during production of the monologue as compared to spontaneous speech due to greater attention being directed towards speech performance when participants knew their speech was being monitored. This finding is consistent with previous reports of performance effects for speakers with PD in clinical and laboratory settings (Keintz et al., 2007; Sarno, 1968; Weismer, 1984). See Table 1 for

a summary of mean intelligibility scores and standard deviations by condition and speech task for the two speaking groups.

Table 1. Mean intelligibility scores and standard deviations (in parentheses) by condition and speech task for the two speaker groups (from Bunton & Keintz, 2008).

Speaker Group	Speech Task	Spontaneous	Single Task	Dual Task
CG	Single words		99.09 (0.4)	98.7 (0.7)
CG	Sentences		98.09 (1.0)	98.8 (1.1)
CG	Monologue	98.4 (2.4)	97.45 (0.8)	97.6 (0.9)
PD	Single words		90.75 (5.9)	81.15 (11.3)
PD	Sentences		90.2 (4.2)	78.28 (13.8)
PD	Monologue	74.25 (14.3)	87.5 (7.4)	73.52 (13.1)

In the **dual-task condition** (speaking + nut/bolt assembly), data for control participants and participants with PD show similar intelligibility scores for all three speech tasks. There were no significant differences between any speaking conditions when subjects performed the dual-task.

Again, the authors surmised that in previous studies, differences in the intelligibility of participants with PD across tasks may have related to location and communication partner. Therefore, previous findings may not be directly comparable to the present results. Furthermore, the current results found that dual-task monologues and spontaneous speech samples were more challenging to speakers with PD than single-task monologues. Thus, similarities in the performance across overt dual-task monologues and covert spontaneous speech samples support the use of dual-task paradigms to obtain more representative measures of functional intelligibility as compared to single-task clinical or laboratory speech measures.

Tjaden and Wilding (2010) also found negligible benefit from the provision of external cues in 12 participants with PD, who demonstrated similar speech performance in both reading

and monologue tasks. In the study, intelligibility estimates were obtained for a reading passage (the John Passage), and an extemporaneous two minute monologue. Ten of the participants had hypokinetic dysarthria, one had hyperkinetic, and one presented with hypo-hyperkinetic dysarthria. Dysarthria severity level was evaluated by three Speech-Language Pathologists and determined to range from mild to severe. Sixty listeners (M age = 32) judged intelligibility for the reading passage using orthographic transcription and modulus-free direct magnitude estimation (DME). To minimize familiarity effects, each listener orthographically transcribed a random ordering of reading passage runs produced by one speaker and scaled intelligibility of a random ordering of reading passage runs produced by a second speaker using DME. Hence, a given listener only heard the content of the reading passage twice. A speech run was operationally defined as, “a stretch of speech bounded by a silent period or pause between words $\geq 200\text{ms}$ ”. For orthographic transcription, listeners were instructed to write down what the speaker said as accurately as possible. A percent correct score was obtained for each speech run by tallying the number of correctly transcribed words completed by five listeners, dividing by the total number of words, and multiplying by 100. An overall percent correct score for each listener also was obtained by tallying the total number of words correctly transcribed, dividing by the total number of possible words, and multiplying by 100. For DME, intelligibility was operationally defined as 'the ease with which speech is understood'. These scaled estimates of intelligibility were converted to a common scale (Engen, 1971) and an overall mean for each speaker was calculated.

An additional 10 listeners (M age = 25) were recruited to scale intelligibility of speech runs for the monologue task using DME. Speech runs for all speakers were pooled and two

random orderings of the stimuli were generated for presentation to listeners. Scaled estimates for the monologue task were converted and averaged in the same way as for the reading passage DME scoring.

Results demonstrated that scaled estimates of intelligibility for paragraph reading and monologue tasks were not significantly different. These results concur with findings from Bunton and Keintz (2008) discussed earlier, and suggest, according to the authors, that scaled estimates of intelligibility for reading show potential for indexing intelligibility of an extemporaneous monologue. However, methodological issues within the study raise concerns for these results to be generalizable to other individuals with PD. The authors report that listeners found the task of numerically scaling intelligibility, in the absence of an anchor or modulus, to be unusual. As a result, the intrajudge and interjudge reliability for the scaling task was less than robust. Using Kendall's tau-b to ascertain reliability for DME, the reading passage intrajudge reliability yielded a matrix of concordant pairs with significant coefficients ($p < 0.05$) ranging from 0.44 – 0.68 (M 0.53; SD 0.13) and interjudge coefficients ranging from 0.27 – 0.42 (M 0.33; SD 0.04). Similarly, for the monologue task, intrajudge reliability coefficients ranged from 0.23 – 0.67 (M 0.44; SD 0.17) and interjudge coefficients ranged from 0.21 – 0.58 (M 0.42; SD 0.10). These factors show that conclusions from the DME procedure should be considered with caution.

Keeping in mind the issue with reliability, findings from Tjaden and Wilding (2011), as well as Bunton and Keintz (2008), demonstrate similar ratings of intelligibility for reading and monologue speech tasks. These outcomes differ from reports indicating poorer intelligibility for monologue in PD, compared with structured speech materials such as reading words and

sentences (Canter & Van Lancker, 1985; Kempler & Van Lancker, 2002; Sidtis et al., 2012).

Tjaden and Wilding (2011) and Bunton and Keintz's (2008) findings also differ from studies reporting that externally cued movements for individuals with PD are superior to self-initiated movements (Burleigh-Jacobs et al., 1997; Cunnington et al., 1999; Freeman et al., 1993; Georgiou et al., 1994; Lehman et al., 2005; Majsak et al., 1998; Mak et al. 2004; McIntosh et al., 1995; Morris et al., 1996; Thaut et al., 1996). As such, Tjaden and Wilding (2011) suggest caution in assuming that findings from the general motor control literature extend to speech in PD.

To summarize, a review of the speech literature on task-based differences reveals that some investigators suggest intelligibility is negligibly changed when an external auditory or visual cue is provided, and therefore similar in monologue and reading conditions (Bunton and Keintz, 2008; Tjaden and Wilding, 2011), while a small but growing body of speech literature suggests that individuals with PD speak more intelligibly during speech tasks that provide an external model (e.g., reading, repeating) compared to spontaneous speech tasks (Kempler & Van Lancker, 2002; Sidtis et al., 2012). Given these inconsistent findings, along with limited investigations, future studies are warranted to gain a clearer picture of task-based differences in speech and the impact of external and internal cueing mechanisms. (See Table 2 for a summary of internal vs. external cueing speech studies).

Study	Participants	Indicators of severity	Speaking tasks	Listener's judgments	Findings	Methodological concerns
Canter & Van Lancker (1985)	Case Study: • 45 y/o male s/p BL thalamic surgery for the relief of PD symptoms • 1 healthy control	• Mild/Moderate articulatory deficits • No indication of physical severity • Yrs since diagnosis = 17	1. Monologue 2. Reading (Rainbow Passage)	• 58 college students • Items presented in classroom with volume set to comfortable level • Written transcription • 32 listeners transcribed 40 phrases (4-7 words in length) extracted from the reading passage (20 from PD + 20 from Ctl). 26 listeners transcribed 40 phrases extracted from the monologue (20 from PD + 20 from Ctl). Intelligibility was calculated using 40 target words per task per speaker.	Intelligibility: • Control Reading = 95% Monologue = 97.5% • PD Reading = 31% Monologue = 23%	1. Lacked recording specification 2. Intelligibility was calculated from 40 target words (from the extracted phrases) versus connected speech 3. Repeated stimuli for reading passage. Listeners may become familiar with passage. 4. Inconsistent listening level 5. Inconsistent number of listeners per group (32 for reading passage, 26 for monologue) 6. Small sample
Kempler & Van Lancker (2002)	Case Study: • 74 y/o male	• Moderate hypokinetic dysarthria • Hoehn & Yahr = Level 2 • Yrs since diagnosis = 18	1. Monologue 2. Reading phrases extracted from monologue	• 64 listeners age 23-78 • Items presented in soundfield with volume set to comfortable level • 10 monologue phrases; same phrases also read aloud by participant • Written transcription "cloze" format • Listeners transcribed one target word per stimulus item (20 items total per task) onto blank lines on answer sheet.	Intelligibility: • Reading = 78% • Monologue = 29%	1. Intelligibility was calculated from 20 target words (from extracted phrases) versus connected speech 2. Inconsistent listening level 3. Small sample
Bunton & Keintz (2008)	• 4 PD • 4 controls • Ages 62-71	• Diagnosed with hypokinetic dysarthria • Intelligibility ○ Spontaneous = 74% • Hoehn & Yahr = All Level 3 • Yrs since diagnosis not provided	1. Read 71 monosyllabic words 2. Read 60 low predictability sentences 3. Monologue 4. Spontaneous speech sample recorded covertly Conditions: 1. Speech only 2. Dual task (speech + nut/bolt)	• 96 listeners age 18-50 • Items presented via speaker with volume held constant • Written transcription • Each listener heard one speaker with PD then one control produce each of the following tasks: ○ 71 words ○ 30 HINT sent ○ 60 monologue runs ○ 60 spontaneous runs • To control for listener familiarity with the sentences, only half from each speaker were played within a listening session.	Single Task Condition: • Data for control & PD participants show similar intelligibility scores for all 3 speech tasks (single words, sentences, monologue) • Significant difference between spontaneous & monologue in PD only. Dual Task Condition: • Data for control & PD participants show similar intelligibility scores for all 3 speech task, including between spontaneous & monologue Single vs. dual task significant for all 3 speech tasks for PD only.	1. No reported yrs since diagnosis 2. Small sample
Tjaden & Wilding (2011)	• 12 PD • 6M, 6F • Ages 42-81	• Mild-Severe dysarthria ○ 10 hypokinetic ○ 1 hyperkinetic ○ 1 hypo/hyper • No indication of physical severity • Yrs since diagnosis = ○ 1-17 (M = 7.25)	1. Monologue 2. Reading passage (John Passage)	• 60 listeners, mean age 32 • Items presented over headphones in booth. Volume controlled and held constant via custom software • Written transcription + DME of speech runs	• Scaled estimates of intelligibility for reading & monologue were not significantly different	1. Calculation of scaled scores not clearly described 2. Intrajudge and interjudge reliability for transcription and DME was not robust. 3. DME procedure confusing to listeners
Sidtis et al. (2012)	• 6 PD • 5 PD w/DBS Groups age: • PD 60-73 • PD w/ DBS 56-62	• Mild hypokinetic dysarthria (all 11) • No indication of physical severity • Yrs since diagnosis = ○ PD: 7-15, M=10 ○ PD w/DBS: 9-15, M=11.2	1. Monologue 2. Repetition of phrases extracted from monologue	• 30 listeners age 17-82 • Items presented over headphones adjusted to comfortable listening level. • Written transcription to fill in 426 target items in 170 utterances (cloze format). Following each item, a 5 point rating scale was completed to rate difficulty level in understanding the utterance.	• For all three groups, PD, PD/DBS ON, & PD/DBS Off, repetition trended more intelligible than monologue but was not significantly different, possibly due to mild level of hypokinetic dysarthria.	1. All mildly dysarthric participants, thus intelligibility not greatly impacted. 2. On average, PD w/DBS participants were 9 years younger. 3. Inconsistent listening level 4. Relatively small sample size

Table 2. Studies examining task-based changes to connected speech.

Other factors related to the examination of task-based speech changes in PD

Speech Naturalness

One missing element that may help in the clarification of task-based changes to connected speech is naturalness. Duffy (2013) explains that naturalness aids in the transmission of linguistic and paralinguistic information that interacts with semantic, syntactic, morphologic, and pragmatic domains of language to convey meaning. When naturalness is impaired, the listener may perceive speech as monotonous or unpredictably variable. When pitch, loudness, and durational characteristics of speech are out of sync, the speaker may send contradictory messages, negatively impacting communication. Often times, naturalness is the main speech impairment noted in individuals with hypokinetic dysarthria, more so than intelligibility (Duffy, 2013; Yorkston et al., 1999). A closer examination of naturalness as it relates to speaking tasks may help to clarify the effect external versus internal cues have on speech production. Thus, in the proposed study, naturalness will be included as a perceptual feature to be rated by listeners along with understandability.

The Need for a Clinical Comparison Group

To help determine if differences between internally versus externally cued tasks are driven by disrupted internal triggers or simply attentional focus, participants with ataxic dysarthria from cerebellar disease will be included as a clinical comparison group. The cerebellum is another primary motor control circuit and, like the basal ganglia, the cerebellum is also involved with movement selection and guidance (Marsden & Harris, 2011; O'Sullivan & Schmitz, 2007). The cerebellar circuitry helps to coordinate the timing between the single components of a movement, scales the size of muscular action, and coordinates the sequence

of agonists and antagonists (Diener & Dichgans, 1992). In regards to speech, it has been suggested that the cerebellum plays a crucial role in programming stored speech patterns for execution of prosodically normal utterances with appropriate rate, tempo and emotional stress (Ackermann et al., 2007). Functional differences between the basal ganglia and cerebellum, however, lie in how they utilize internal and external cues. Research suggests that the basal ganglia may be particularly concerned with internally generated movements, while the cerebellum is involved in visually triggered and externally guided movements (Shumway-Cook & Woolacott, 2012). In fact, the classic ataxic triad of dysmetria, dysynergia, and dysdiadochokinesis may be rooted in part in an inefficient processing of sensory information needed to produce accurate and well-timed movements (Kent et al., 2000). While individuals with PD have “scaled down” motor output that can often be overcome with an external cue, this pattern does not hold for individuals with cerebellar disease. The motor coordination/regulation impairment from the ataxia is present regardless of context (Brown et al., 1970; Cannito & Marquardt, 1997; Duffy, 2013; Kent et al., 1997, 2000). Following execution of a motor act, the dysfunctional cerebellum is no longer able to use external information to check and correct the accuracy of productions. Thus, external cueing does not lead to a dramatic change in performance. Therefore, it is predicted that ataxic speakers will not perform better when provided an external cue and as a result, understandability will be similar for both the reading and monologue tasks. This finding would support the hypothesis that the dysfunctional basal ganglia is lacking an adequate, internally generated model and speakers with PD become overly reliant on external cues to guide skilled movement.

The proposed study is designed to answer the following research question:

- What is the effect of an externally cued speaking task (reading) vs. an internally cued speaking task (covert conversation) on the perceived understandability and naturalness of the speech of individuals with hypokinetic dysarthria from PD & ataxic dysarthria from cerebellar disease?

It is predicted that understandability and naturalness will be perceived more favorably in a speech elicitation condition that provides an external model (i.e., reading) versus one that relies on an internal model (i.e., conversation) for individuals with PD. Conversely, it is predicted that understandability and naturalness will be perceived similarly for speech elicited via external and internal models for speakers with cerebellar impairment. This finding would support the hypothesis that the dysfunctional basal ganglia is lacking an adequate, internally generated model and speakers with PD become overly reliant on external cues to guide skilled movement. Speakers with cerebellar disease are not expected to be aided by external cues. If, however, both groups benefit similarly from the external cue condition, the likely explanation is that the reading task requires less cognitive/linguistic processing than the spontaneous speech task and/or directing of increased attentional focus to the task of speaking (see Table 3).

Table 3. Hypothesis Table

	PD	Cerebellar	Interpretation
H₀	Conversation = Reading	Conversation = Reading	Fail to reject null hypothesis
H₁	Conversation < Reading	Conversation = Reading	This finding would support the hypothesis that the dysfunctional basal ganglia is lacking an adequate, internally generated model and speakers with PD become overly reliant on external cues to guide skilled movement. Speakers with cerebellar disease are not aided by external cues, likely because impaired internal mechanisms responsible for the generation of an internal model are unable to use external cues to aid in accurate programming and guidance of skilled movement.
H₂	Conversation < Reading	Conversation < Reading	If both groups benefit similarly from the external cue condition, the likely explanation is that the reading task requires less cognitive/linguistic processing than the spontaneous speech task and/or increased attentional focus.

Methods

Participants:

Participants were consented before study participation in accordance with the Institutional Review Board of the University of Washington. Both speakers and listeners were paid for their participation in the study.

Speakers:

A total of 16 adults completed the study: 10 diagnosed with PD (nine with hypokinetic dysarthria and one with hypokinetic plus probable spastic dysarthria) and 6 individuals with CD (five ataxic dysarthria and one with ataxic plus probable spastic dysarthria). The group with PD had nine males and one female ranging in age from 59-78 ($M = 69.7$, $SD = 5.5$). The group with CD had five females and one male, ages 41-73 ($M = 58.5$, $SD = 11.4$). See Table 4 for a summary of descriptive characteristics. All participants were native speakers of American English; had adequate visual acuity demonstrated by accurately reading line 20/30 at 2.3 feet from the Snellen chart; adequate hearing thresholds ≤ 50 dB at 500, 1000, and 2000 Hz; typical speech, language, and cognitive developmental history; and PD or CD diagnosis by neurologist (per self-report). Participants continued taking their prescribed medications during the experiment. To control for medication use, speakers were scheduled during their optimal medication period (one-to-two hours after medication, per self-report). Recruitment targeted individuals with mild to severe dysarthria determined through the screening process and verified by two expert listeners who are both Speech-Language Pathologists and researchers with more than twenty years experience working with the targeted populations. The expert listeners heard a sample of connected, spontaneous speech from each participant that had been recorded, digitized at a

14,000 Hz sampling rate, and played back in a quiet room using Adobe Audition 9.0. The speakers were rated perceptually on both understandability and naturalness using a four-point scale (i.e., normal, mild, moderate, severe), with experts reaching 100% agreement on all samples. In cases where mixed dysarthria was possible (i.e., ataxic with spastic), it was agreed that the predominant dysarthria was hypokinetic or ataxic. All participants were at least 5 years post diagnosis ($M = 10.6$ years, $SD = 6.2$). Participants were excluded for prior neurosurgical procedures including Deep Brain Stimulation (DBS).

Table 4. Characteristics of participants with Parkinson’s Disease (PD) and Cerebellar Disease (CD).

Participant	Gender	Age	Years of Education	Etiology	Dysarthria Type	Severity Level- U	Severity Level- N	Years Since Diagnosis
PD1	M	74	20	PD	Hypokinetic	MOD	MOD	18
PD2	M	65	16	PD	Hypokinetic	MILD	MILD	8
PD3	M	72	16	PD	Hypokinetic	MOD	MILD	8
PD4	F	59	16	PD	Hypokinetic (+ spastic?)	MILD	MILD	20
PD5	M	73	16	PD	Hypokinetic	MOD	MOD	10
PD6	M	71	19	PD	Hypokinetic	SEV	SEV	10
PD7	M	64	18	PD	Hypokinetic	SEV	SEV	5
PD8	M	70	18	PD	Hypokinetic	MILD	MOD	5
PD9	M	78	18	PD	Hypokinetic	MILD	MILD	7
PD10	M	73	18	PD	Hypokinetic	MOD	MILD	5
Mean	9 M, 1 F	69.7	17.5					9.6
SD		5.5	1.4					5.3
CD1	F	60	17	CB Stroke	Ataxic	MILD	MILD	6
CD2	M	73	12	SCA6	Ataxic	SEV	MOD	20
CD3	F	41	18	Friederich’s Ataxia	Ataxic	MILD	MILD	22
CD4	F	53	14	SCA3	Ataxic	MILD	MILD	11
CD5	F	68	18	Progressive CB Ataxia	Ataxic	MILD	MOD	2
CD6	F	56	14	Progressive CB Ataxia	Ataxic (+ spastic?)	MILD	MOD	12
Mean	1 M, 5 F	58.5	15.5					12.2
SD		11.4	2.5					7.8

Note. U = Understandability; N = Naturalness; MOD = Moderate; SEV = Severe, CB = Cerebellar; SCA = Spinocerebellar Ataxia

Participants were required to successfully pass a depression and cognitive screening.

Specifically, participants needed to score ≤ 13 on the *Beck Depression Inventory II* (Beck, Steer,

& Brown, 1996) and ≥ 25 on the *Mini-Mental Status Exam* (Folstein, Folstein, & McHugh, 1975). No participants were excluded based on these standardized screening measures. However, out of a total of 21 participants originally recruited for the study, 5 participants with PD were excluded for not having a discernible dysarthria. This yielded a final count of 16 eligible participants.

Listeners:

Ten licensed speech-language pathologists with a minimum of five years clinical experience (Bunton et al., 2007) participated in the study as experienced listeners. Clinically experienced listeners were selected over untrained listeners given their attuned listening skills and given that they are the healthcare professional responsible for diagnosing disordered speech in this population. Additionally, it has been suggested that higher intra- and inter-rater reliability exists for experienced listeners versus inexperienced listeners (Zeplin & Kent, 1996). All listeners were native speakers of American English with no history of speech or language deficits per self-report. Listeners passed a bilateral pure-tone hearing screening at 25dB, for the frequencies 500, 1000, 2000, and 4000 Hz and a vision screening by correctly reading the 20/30 line of a Snellen chart while standing 2.3 feet away (participants were allowed to wear corrective lenses). No listeners were excluded based on these qualifications. However, out of a total of 11 persons originally recruited, one was unable to complete the study due to technical error. This yielded a total of 10 experienced listeners. The clinical practice setting of listeners varied across the continuum of care, with the majority being outpatient clinics. On average, years of clinical experience ranged from 5 to 40 with a mean of 13.8 and standard deviation of 10.8. See Table 5 for a full description of listener characteristics.

Table 5. Characteristics of experienced listeners (EL)

Expert Listener	Gender	Age	Years of Education	Years of Practice	Primary Setting
EL 1	M	59	18	15	Outpatient
EL 2	F	33	18	9	Outpatient
EL 3	F	34	18	10	Outpatient
EL 4	F	47	26	10	Acute
EL 5	F	34	18	6	Outpatient
EL 6	M	68	20	40	Acute
EL 7	F	29	18	5	Acute
EL 8	F	52	20	20	Outpatient
EL 9	F	31	18	5	Outpatient
EL 10	F	43	18	19	Outpatient
<i>Mean</i>		<i>43</i>	<i>20.2</i>	<i>13.8</i>	
<i>SD</i>		<i>13.3</i>	<i>4.3</i>	<i>10.8</i>	

Procedures:

Speaker Session: When participants arrived, they were seated comfortably at a table in a quiet room next to the experimenter. On the table were a computer monitor, mouse, and keyboard from which the experimenter could run the protocol. Following informed consent, all participants were asked to complete a brief questionnaire and were required to successfully pass the screening measures described earlier. Participants were then fitted with an AKG C520 head mounted microphone (constant mouth to microphone distance = 2"). The microphone was connected via MAudio hardware to the USB port of the experimenter's computer running a custom MATLAB speech recording program. Microphone recording level was held constant for all speakers and digitized at a sampling rate of 44,000 Hz. To elicit a covert **speech sample**, the experimenter pretended to continue setting up equipment while engaging the participant in conversation. Unbeknownst to the speaker, the head mounted microphone was turned on to capture a recording of the participant's conversational speech without their awareness of being recorded. Conversation was achieved by the experimenter asking the speaker open-ended

questions and/or requesting more information (e.g., “What is the book you’re reading?”, “Tell me more about your garden.”, etc.) until three minutes of speech was obtained. Once an adequate speech sample was captured, the experimenter informed the participant that his or her speech was being recorded and why the covert recording was needed. The participant then signed a second informed consent form per the University of Washington’s Institutional Review Board requirements. After obtaining the second consent, the experiment continued with the speech evaluation which consisted of: sustained phonation, diadochokinetic (DDK) rates, and the sentence portion of the Speech Intelligibility Test (SIT) for Windows (Beukelman, Hakel, & Yorkston, 1996). See Table 6 for testing results. The participant was then offered a 10 minute break (microphone remained in place) while the examiner listened to the covert speech recording and extracted the first eight sentences of 5-15 words in length that met pre-specified criteria (see Appendix A); five to be used for analysis and three additional sentences to be used as replacement if warranted. For eight participants, one of the extra sentences had to be used due to clipping difficulties (e.g., clipping resulted in an unnatural bleeping sound), one participant required the use of two extra sentences due to clipping difficulty, and three individuals required the use of one extra sentence due to the voice of the experimenter being audible. The sentences were typed into a Microsoft Word document using 20 pt. Arial font, double spaced. When the participant was ready, he/she was instructed to, “read each sentence aloud using your typical speech” while being recorded. The participant was able to read the sentences directly off of the computer screen. Sample sentences were free of proper nouns, low frequency words, formulaic expressions, and specialty vocabulary (Sidtis et al., 2012). Words were used if understandable given context. If the word was unintelligible, the

experimenter verified the questionable word(s) with the speaker prior to the reading task. The mouth-to-microphone distance was double checked for accuracy prior to recording of sentences. The reading samples were recorded using the same procedure as the covert recording. The total experiment completion time for each participant ranged from 60 – 90 minutes.

Table 6. Sentence Intelligibility Test (SIT; Yorkston, Beukelman, & Hakel, 1996) results and experienced listener ratings scores.

Participant	Percent Intelligible	Speech Rate (WPM)	Intelligibility Rate (WPM)	Communication Efficiency Ratio	Severity Rating-U	Severity Rating-N
PD1	96	199	191	1.00	MOD	MOD
PD2	97	193	187	0.98	MILD	MILD
PD3	96	146	139	0.74	MOD	MILD
PD4	93	150	130	0.73	MILD	MILD
PD5	89	138	123	0.65	MOD	MOD
PD6	45	269	122	0.64	SEV	SEV
PD7	82	148	121	0.63	SEV	SEV
PD8	98	249	245	1.29	MILD	MOD
PD9	97	207	202	1.06	MILD	MILD
PD10	91	228	207	1.09	MOD	MILD
<i>Mean</i>	<i>88.4</i>	<i>192.7</i>	<i>166.7</i>	<i>0.88</i>		
<i>SD</i>	<i>16.0</i>	<i>46.5</i>	<i>(44.86)</i>	<i>0.23</i>		
CD1	95	126	120	0.63	MILD	MILD
CD2	77	100	77	0.40	SEV	MOD
CD3	94	165	155	0.82	MILD	MILD
CD4	99	171	169	0.89	MILD	MILD
CD5	97	66	64	0.34	MILD	MOD
CD6	97	65	63	0.33	MILD	MOD
<i>Mean</i>	<i>93.2</i>	<i>115.5</i>	<i>108</i>	<i>0.57</i>		
<i>SD</i>	<i>8.1</i>	<i>46.7</i>	<i>46.9</i>	<i>0.25</i>		

Note. U = Understandability; N = Naturalness; WPM = Words Per Minute; Mod = Moderate, SEV = Severe

Intelligibility Rate – The rate of intelligible speech taking into account both accuracy and speaking rate.

Communication Efficiency Ratio – The rate of intelligible speech produced by a participant divided by the normal rate of intelligible speech on SIT tasks (190 WPM). The ratio allows for comparison of obtained intelligibility rates to typical adults. A ratio of 1 can be interpreted as the average intelligible speech per minute of a healthy adult speaker. The further a participant's score is from 1.0 (+ or -), the further their intelligibility is from a typical, healthy speaker.

Procedural Specifications

The covert conversational speech and reading samples were recorded using custom written software in MATLAB. To run the software, the experimenter would enter all identifying participant codes and sample information into the program's command window. Once entered, a graphical menu was displayed prompting the experimenter to click the start button when ready to initiate recording. The menu also allowed for pausing, resuming, and ending the recording as needed. Once ended, the recording was terminated and automatically formatted and saved as a 16 bit, 44,000 Hz wave file. This procedure was used to capture the covert conversational speech sample, sustained phonation, DDKs, sentence reading from the SIT, and reading of the extracted sentences. To capture the covert speech sample, the experimenter had the program open and information entered prior to arrival of the participant. The recording menu was small enough that it could easily be hidden from the participant's view on the experimenter's computer desktop. As an added precaution, the experimenter turned his computer screen slightly away from the participant's direct line of view. When the time came to record the covert conversation, the experimenter could easily click the "record" button while pretending to "set-up equipment".

To extract sentences, the covert recording was opened in Adobe Audition 9.0, allowing the experimenter to listen to the conversational sample using Sony Professional MDR-7506 headphones. The sentences from the covert- conversation file were then clipped and processed as needed in sound editing software (Adobe Audition 9.0). Following reading of the extracted sentences, each participant had a final 10 sentences (5 covert- conversation + the same 5

sentences read) each saved as individual wave files that were later used for rating by experienced listeners.

During the listener session, a different custom written MATLAB software (See Appendix B), was used to retrieve the files and play them back in a random order. The total number of listening samples generated for the PD group was: 10 speakers x 10 sentences [5 reading + 5 covert] = 100 stimulus items plus 20 repeated files to test intra-rater reliability (20 percent of the PD total), for a total of 120 total stimulus items. For the cerebellar group, 6 speakers x 10 sentences [5 reading + 5 covert] = 60 stimulus items plus 12 repeated files for reliability purposes (20 percent of the CD total), for a total of 72 stimulus items. Combining the PD samples (120) and the CD samples (72) resulted in a grand total of 192 samples. Each expert listener had to make two judgments (“understandability” and “naturalness”) per sample resulting in 384 judgments per listener (See Table 7).

Table 7. Number of perceptual judgments per group and speaking task.

	Monologue	Reading	Totals	
PD 1 ↓ PD 10	5 sentences	Same 5 sentences	10 sentences x <u>10 participants</u> = 100 sentences + 20 repeated = 120 items	120 sentences x 2 perceptual ratings = 240 ratings for PD
CD 1 ↓ CD 6	5 sentences	Same 5 sentences	10 sentences x <u>6 participants</u> = 60 sentences + 12 repeated = 72 items	72 sentences x 2 perceptual ratings = 144 ratings for CD
				384 total ratings per listener

Note. PD = Parkinson’s disease, CD = cerebellar disease.

Listener Session: Following consent and the screening procedures described earlier, participants were moved to a quiet room and seated comfortably at a table with a computer monitor and wireless computer mouse. A visual analogue scale (VAS) (see Figure 1) was displayed on the screen and could be used by the experimenter when providing task directions.

It was explained to the listener that he or she would need to press the “PLAY” button when ready to start the listening session. By doing so, she/he would hear a sound file played only once. After listening to the entire sound file, the listeners were asked to use their best clinical judgment and rate each of the samples on the two different dimensions, understandability and naturalness, by sliding the cursor along the VAS. Throughout the session, the VAS for both dimensions was visible on the computer screen while each sample was played. The software program was designed to convert the position of the cursor on each VAS into a numerical value between 1 and 100 which was then later used for analysis. Perceptual dimensions and VAS anchors were clearly defined for listeners using the following definitions: *Understandability* – “the speaker’s articulatory precision”, with the two ends of the scale labeled as “completely understandable” and “completely unable to understand”; and *Naturalness* – “the speaker’s prosody – defined as speech rate, rhythm, intonation, stress patterns and loudness” with the two ends of the scale labeled as “completely natural” and “highly unnatural.” Definitions of each dimension were provided on the computer monitor just above the VAS throughout the entire session. Task directions and definitions were provided in written form as well. See Appendix C for a full description of verbal and written directions provided to each experienced listener. Once the listener indicated full understanding of the task and definitions, they were fitted with Sony Professional MDR-7506 headphones and proceeded to press the “PLAY” button, initiating the program.

After providing both perceptual ratings, the listeners were instructed to press the “NEXT” button and then “PLAY” button in order to advance to the next sample. The same procedure: 1) “PLAY”, 2) use the VAS to provide two ratings, 3) “NEXT”, “PLAY”, etc., was

followed throughout the session until all 192 sound files were rated. The MATLAB program was designed to keep track of the sample number in a small window at the top of the screen. This allowed for the participant and experimenter to monitor progress. Each listener heard a random ordering of the original sound files (100 PD + 60 CD = 160) first, followed by a random ordering of repeated sound files (20% of total = 32) used to determine intra-rater reliability. Headphone volume was set by an expert listener with normal hearing thresholds (< 25dB, for the frequencies 500, 1000, 2000, and 4000 Hz). Once set, the volume remained constant between listeners. The program saved the perceptual ratings in MATLAB format as well as in a Microsoft Excel file for later analysis. The judges' ratings for all utterances produced by the individual participants were averaged by measure, yielding an overall score for each participant on understandability and naturalness.

Participant ID

COUNTER
0

SAVE NOW

Understandability- the speaker's articulatory precision.

Naturalness- the speaker's prosody- defined as speech rate, rhythm, intonation, stress patterns and loudness.

unable to understand completely understandable

0 50 100

highly unnatural completely natural

0 50 100

PLAY NEXT

Figure 1. Visual analogue scale experienced listeners used for rating speech samples.

Calibration Methods

The microphone signal was calibrated to enable measurement of absolute SPL values (see Winholtz & Titze, 1997). A RadioShack model 33-4050 sound level meter was positioned 30 cm from the lips of a healthy adult speaker using C frequency weighting and measured using a

slow response setting. The SPL measurement was completed while the speaker simultaneously produced a sustained /a/. The SPL of the speaker at 30 cm was 76dB.

The intensity levels of speech stimuli presented by Sony Professional MDR-7506 were measured using an AEC100 acoustic ear and a Larson Davis System 824 Sound Level Meter. The right earphone was placed on the acoustic ear to obtain an average intensity level on a dBA scale. For a sustained phonation produced by a healthy adult speaker using identical recording parameters, the output at the earphone was within +/- 3 dB of the measured input level (76dB). The average intensity level (in dBA) was also obtained for all 160 sound files. Mean headphone output levels ranged from 48.5 dBA to 71.4 dBA. See Table 8 for mean (SD) per participant.

Table 8. Mean SPL in dBA per participant, per condition and overall means (SD) per group.

Participant	Covert M SPL in dBA	Reading M SPL in dBA	Combined M SPL in dBA
PD1	54.8	64.9	59.8
PD2	60.7	59.6	60.2
PD3	55.5	57.6	56.5
PD4	67.5	64.8	66.1
PD5	64.1	64.2	64.1
PD6	50.1	48.5	49.3
PD7	49.7	51.3	50.5
PD8	60.1	62.0	61.0
PD9	57.3	64.1	60.7
PD10	53.4	51.7	52.5
Mean	57.3	58.9	58.1
SD	5.8	6.3	5.7
CD1	67.4	71.4	69.4
CD2	71.3	70.2	70.7
CD3	62.3	62.5	62.4
CD4	54.7	49.1	51.9
CD5	60.5	62.9	61.7
CD6	67.9	64.9	66.4
Mean	64.0	63.5	63.8
SD	6.0	8.0	6.8

RESULTS

Reliability

To assess reliability of the sentence extraction method, inter-rater reliability was calculated between the investigator and two research assistants who received training in the extraction procedure. The reliability was run on 38% of the total participants (6 out of 16). A word to word comparison was used for each sentence, with contractions counting as one word. If a sentence was extracted that did not coincide with the researcher's extraction, that sentence would receive a score of 0. However, if the following sentence(s) were in agreement, just misaligned, they would receive points per words matched and so forth. All measures of inter-rater reliability were calculated using the intraclass correlation coefficient (ICC) (group averages model). A standard acceptance criteria of .7 was determined *a priori* (Nunnally & Bernstein, 1994). For the sentence extraction procedure, a high degree of reliability was demonstrated between raters (.891).

To assess intra-rater reliability, 20% of the samples were repeated for each listener. Cronbach's alpha was used to assess reliability. A standard acceptance criteria of .8 was determined *a priori* (Cortina, 1993). Reliability was sufficiently high for both Understandability ($\alpha = .945$, range .77 - .97) and Naturalness ($\alpha = .924$, range .74 - .94).

Inter-rater reliability was calculated to assess the level of agreement between listeners 1 through 10 using the intraclass correlation coefficient (ICC) (group averages model). A high degree of reliability was demonstrated for both Understandability (.867, range .83-.89), and Naturalness (.874, range .84-.89).

Group Analysis

Prior to analysis, listener ratings were collapsed across the 5-15 word sentence lengths, giving an average rating of Understandability and Naturalness for each speaker. Collapsing across sentences was necessary to meet the assumption of independence.

Understandability

A 2 (Etiology) x 2 (Speaking Task) ANOVA on understandability revealed a significant main effect of task type, $F(1,14) = 9.55, p = .008$, such that participants, both PD and CD, were perceived as more understandable in the reading task ($M = 74.53, SD = 18.83$) than in the covert task ($M = 62.98, SD = 24.49$). There was no significant main effect of etiology $F(1,14) = .002, p = .964$, and no interaction between etiology and task type $F(1,14) = 2.44, p = .141$ (Figure 2). However, a paired t-test comparing speaking task for participants with PD revealed a significant difference $t(1,9) = 3.09, p = .013$, such that the reading task ($M=76.29, SD= 22.19$) was perceived as more understandable than the covert conversation task ($M=60.84, SD= 29.03$). Similarly, a paired t-test comparing task type for participants with CD revealed a significant difference $t(1,5) = 3.42, p = .019$, such that the reading task ($M=71.61, SD= 12.72$) was perceived as more understandable than the covert task ($M=66.53, SD= 16.06$) (Figure 3).

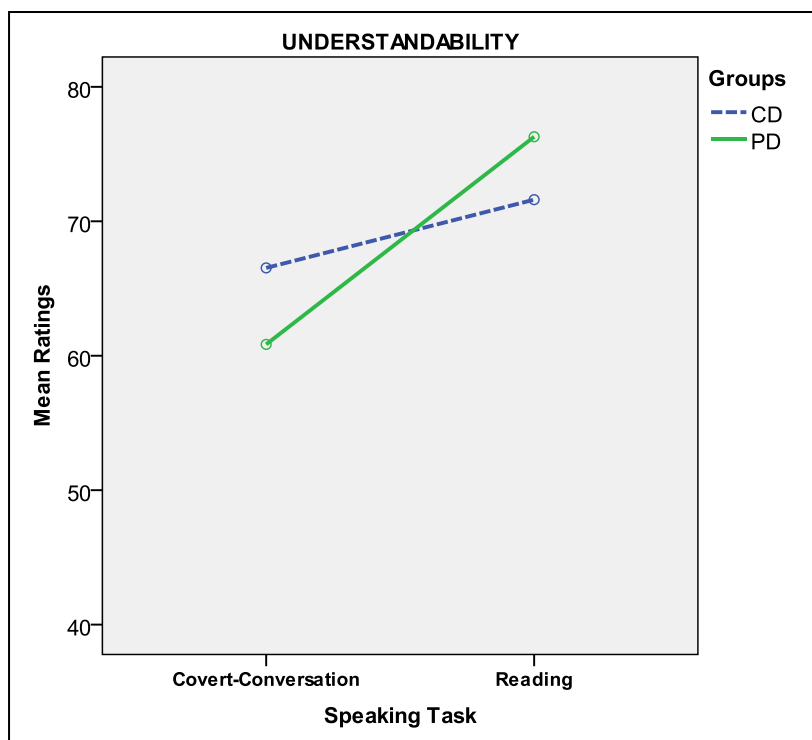


Figure 2. Mean ratings of understandability by expert listeners across conversation and reading tasks for the group with cerebellar disease (CD) and Parkinson's disease (PD).

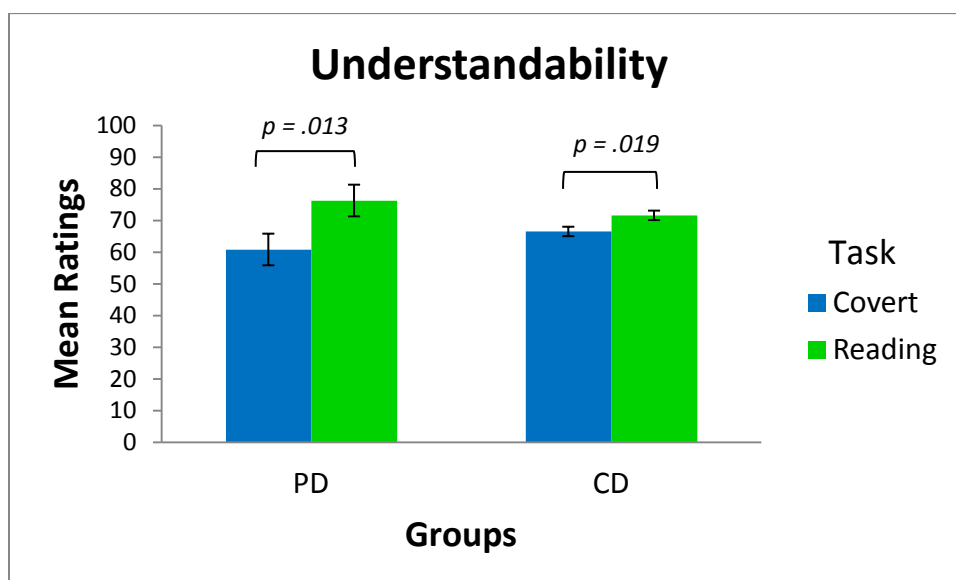


Figure 3. Paired t-test of mean perceptual ratings of experienced listeners for "Understandability" compared across speaking tasks for both groups. Error bars represent standard error for paired t-tests.

Naturalness

A 2 (Etiology) x 2 (Task Type) ANOVA on naturalness revealed a significant main effect of task type, $F(1,14) = 5.34$, $p = .037$, such that participants were perceived as more natural in the reading task ($M = 58.06$, $SD = 21.23$) than in the covert conversation task ($M = 50.69$, $SD = 21.31$). There was no significant main effect of etiology $F(1,14) = .002$, $p = .964$. However, there was a significant interaction between etiology and speaking task $F(1,14) = 7.85$, $p = .014$ (Figure 4). Participants with Parkinson's disease were perceived as speaking more naturally in the reading condition ($M = 64.32$, $SD = 21.50$), than in the covert conversation condition ($M = 51.82$, $SD = 24.50$), $t(1,9) = 3.38$, $p = .008$. However, participants with Cerebellar disease were perceived as equally natural in both reading ($M = 47.62$, $SD = 17.63$) and covert conversation conditions ($M = 48.17$, $SD = 16.61$), $t(1,5) = 1.21$, $p = .279$ (Figure 5).

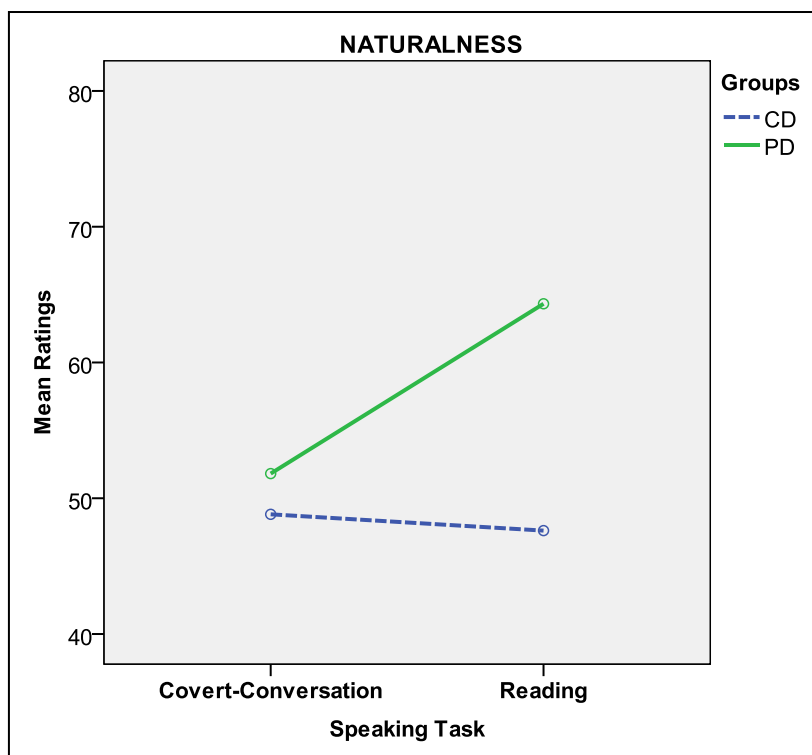


Figure 4. Mean ratings of naturalness by expert listeners across conversation and reading tasks for the group with cerebellar disease (CD) and Parkinson's disease.

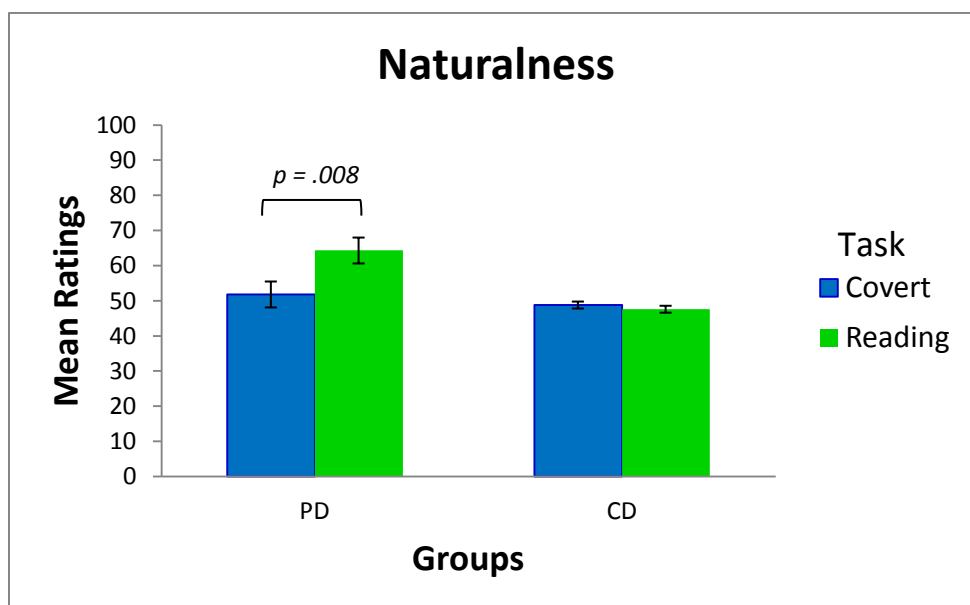


Figure 5. Paired t-test of mean perceptual ratings of experienced listeners for "Naturalness" compared across speaking tasks for both groups. Error bars represent standard error for paired t-tests.

Speech Rate

To determine if rate of speech differed between the covert conversation condition and reading task per group, timed sentence length per sound file was compared using paired t-tests. Results revealed a significant difference in the scores for covert (M = 2.9, SD = 1.4) and reading (M= 2.5, SD= 1.2) conditions; $t(49) = 3.0, p = .004$ for participants with PD. For the cerebellar group, there was a significant difference in the scores for covert conversation (M= 3.5, SD= 1.5) and reading (M= 4.0, SD= 1.6) conditions; $t(29) = 3.4, p = .002$. Thus, for the reading task, the PD group was significantly faster and the CD group was significantly slower (see Table 9).

Table 9. Mean (SD) timed length of sentence in seconds per speech sample.

	PD Group			CD Group		
	Conversation	Reading	t-test	Conversation	Reading	t-test
Mean Rate	2.9	2.5	$t(49) = 3.0$	3.5	4.0	$t(29) = 3.4$
SD	1.5	1.2	$p = .004$	1.5	1.6	$p = .002$

Individual Participant Analyses

Descriptive statistics of experienced listener's perceptual ratings for each participant can be seen in Table 10. To evaluate individual performance patterns for each speaker, differences between speech tasks (covert conversation vs. reading) per perceptual dimension (naturalness and understandability), were averaged across listeners. The average rating for reading was then subtracted from the average rating for conversation for each perceptual dimension. Thus, a positive difference indicates that the speaker was perceived as better during conversation vs. during reading; while a negative difference suggests that a speaker was perceived as better during the reading task. The individual difference scores were then compared to the absolute value of the mean and standard deviation of the group per

dimension. Scores that represent a value more than 1 SD from the group mean were flagged as an indication of marked change in perceptual ratings between speech tasks (see Table 11) (Spencer et al., 2009).

Table 10. Mean (SD) words per sentence and mean perceptual ratings per speaker and task.

Speaker	Mean Words per Sentence	Understandability:		Naturalness:	
		Covert	Reading	Covert	Reading
PD1	7.4 (2.5)	69.5 (19.9)	93.4 (10.0)	52.5 (21.0)	80.7 (18.4)
PD2	8.6 (3.7)	85.6 (14.3)	86.1 (13.8)	75.3 (19.4)	75.9 (18.0)
PD3	8.2 (2.2)	61.2 (24.6)	82.3 (14.2)	50.5 (18.9)	65.0 (23.6)
PD4	9.2 (2.2)	79.4 (16.7)	80.8 (16.2)	55.9 (24.4)	61.6 (22.1)
PD5	10.2 (4.1)	68.8 (22.4)	71.1 (24.4)	52.1 (18.8)	50.6 (22.2)
PD6	5.6 (0.9)	4.2 (8.1)	19.1 (27.2)	8.7 (11.1)	18.5 (18.7)
PD7	8 (1.6)	15.7 (21.2)	69.1 (29.5)	19.1 (18.2)	54.8 (27.0)
PD8	9.4 (1.5)	77.1 (23.6)	90.5 (12.3)	70.9 (24.6)	81.8 (18.8)
PD9	7 (2.0)	91.7 (14.0)	96.9 (6.0)	90.1 (12.0)	96.4 (9.9)
PD10	9.4 (2.3)	55.2 (26.5)	73.6 (22.7)	43.0 (23.0)	58.1 (22.5)
<i>Mean</i>	8.3	60.8	76.3	51.8	64.3
<i>SD</i>	1.4	29.0	22.2	24.5	21.5
CD1	10 (3.7)	80.8 (18.7)	81.9 (14.4)	63.7 (26.6)	60.1 (28.7)
CD2	8 (2.5)	39.7 (23.6)	49.4 (26.4)	26.2 (19.8)	24.2 (22.0)
CD3	9.6 (4.3)	70.2 (23.2)	74.1 (19.3)	57.3 (22.4)	59.6 (23.5)
CD4	7.6 (2.3)	83.4 (19.9)	85.2 (21.6)	68.1 (22.7)	68.6 (27.3)
CD5	6.8 (1.3)	58.3 (24.9)	67.5 (22.7)	37.2 (24.0)	33.2 (19.7)
CD6	8.8 (1.8)	66.8 (16.3)	71.6 (18.1)	40.4 (23.4)	39.9 (21.8)
<i>Mean</i>	8.5	66.5	71.6	48.8	47.6
<i>SD</i>	1.2	16.1	12.7	16.6	17.6

Note. Rating scale ranged from 0 – 100 with 100 representing excellent understandability/precision or naturalness.

Based on difference scores, seven speakers with PD had more than a 5 point increase in understandability while reading compared to two participants with CD. One of the participants with PD was perceived to have a pronounced difference (> 2 SD) in understandability during the reading task while two speakers with CD had greater than one 1 SD difference. These results indicate that for these three participants, reading was perceived as much more understandable by experienced listeners, even more so for the participant with PD.

In regards to perceived naturalness, eight speakers with PD had more than a 5 point increase in naturalness while reading compared to no participants for the cerebellar group. Two

of the speakers with PD had a pronounced difference of greater than 1 SD during the reading task. Thus, experienced listeners perceived the speech of participants with PD as more natural when reading, while no change in naturalness was perceived in speakers with CD.

Table 11. Difference scores (covert conversation - reading) reflecting perceived change with the provision of written text/external cue across perceptual dimensions.

Speaker	Understandability			Naturalness		
	Covert	Reading	Diff*	Covert	Reading	Diff*
PD1	69.5	93.4	-23.9	52.5	80.7	-28.2
PD2	85.6	86.1	-0.5	75.3	75.9	-0.6
PD3	61.2	82.3	-21.1	50.5	65.0	-14.5
PD4	79.4	80.8	-1.4	55.9	61.6	-5.7
PD5	68.8	71.1	-2.3	52.1	50.6	1.5
PD6	4.2	19.1	-14.9	8.7	18.5	-9.8
PD7	15.7	69.1	-53.4	19.1	54.8	-35.7
PD8	77.1	90.5	-13.4	70.9	81.8	-10.9
PD9	91.7	96.9	-5.2	90.1	96.4	-6.3
PD10	55.2	73.6	-18.4	43.0	58.1	-15.1
Mean**	60.8	76.3	15.5	51.8	64.3	12.5
SD**	29.0	22.2	15.8	24.5	21.5	11.7
CD1	80.8	81.9	-1.1	63.7	60.1	3.6
CD2	39.7	49.4	-9.7	26.2	24.2	2.0
CD3	70.2	74.1	-3.9	57.3	59.6	-2.3
CD4	83.4	85.2	-1.8	68.1	68.6	-0.5
CD5	58.3	67.5	-9.2	37.2	33.2	4.0
CD6	66.8	71.6	-4.8	40.4	39.9	0.5
Mean**	66.5	71.6	5.1	48.8	47.6	1.2
SD**	16.1	12.7	3.6	16.6	17.6	2.4

*Diff = Difference (covert conversation minus reading); shaded cells indicate those speakers whose difference score was 1 SD greater than the average difference score of the group (absolute value) per condition.

**Means and SD are based on absolute values of the difference scores.

DISCUSSION

The goal of the present study was to examine the effects of speech task on the understandability and naturalness of persons with PD and CD as perceived by experienced listeners. A direct comparison was made between sentences extracted from a covertly-recorded conversational sample and the reading of those same sentences by the participant. The speech samples were rated by ten experienced listeners (SLPs) using visual analog scales for the perceptual dimensions of understandability and naturalness. It was hypothesized that intelligibility and naturalness would be perceived more favorably in a speech elicitation condition that provides an external model (i.e., reading) versus one that relies on an internal model (i.e., covert conversation) for individuals with PD. Conversely, it was predicted that intelligibility and naturalness would be perceived similarly for speech elicited via external and internal models for speakers with cerebellar impairment.

Both speaker groups were represented by a range of severity levels from mild to severe (see Table 4) as judged by two expert listeners. Moreover, intelligibility testing via the Sentence Intelligibility Test (Beukelman, Hakel, & Yorkston, 1996) revealed comparable speech intelligibility levels, with the group with PD ($M = 88.4$, range 45-98) slightly less intelligible than the group with CD ($M = 93.2$, range 77-99) (see Table 6). Thus, we felt that both impairment groups' baseline speech skills were similar enough to allow for a comparison in their performance.

Overall, results of our investigation revealed that experienced listeners perceived the speech of participants with PD as more natural and more understandable during the reading condition. The cerebellar group also demonstrated a difference between speaking conditions,

but only for understandability. Naturalness was not perceived to change between conversation and reading. Thus, the percept of naturalness appeared to be sensitive to capturing the differences between speakers with Parkinson's disease and cerebellar disease. These results and their implications will be discussed more thoroughly in the sections that follow.

Perceptual Ratings of Naturalness

Naturalness was defined for our experienced listener's as "the speaker's prosody – defined as speech rate, rhythm, intonation, stress patterns and loudness". Based on the listener's ratings, speakers with PD showed a significant improvement in their naturalness from the conversation condition to the reading condition, while speakers with CD did not demonstrate this pattern (see Figures 4 & 5). This finding has several possible explanations.

The most compelling and well-supported explanation is based on the underlying mechanisms that help individuals with PD perform motor skills more accurately when provided external cues (Burleigh-Jacobs et al., 1997; Freeman et al., 1993; Lehman et al., 2005; Majsak et al., 1998; Mak et al. 2004; McIntosh et al., 1995; Morris et al., 1996; Thaut et al., 1996). It may be that the same mechanisms found in the limb motor system are at play during skilled speech movements. There is a large body of limb motor research demonstrating the benefit of external cues to motor performance in PD (i.e., a line on the floor resulting in a normal gait pattern or lines on the paper improving micrographia) (Burleigh-Jacobs et al., 1997; Cunnington et al., 1999; Oliverira et al., 1997). How is it then, that written text provides these same individuals with an external cue, enhancing naturalness of speech production? Perhaps the speaker derives cues from the word spacing and punctuation, which assist the basal ganglia and/or bypasses its impairments, enabling the accurate activation of scaled speech movements (Giladi et al, 1997;

Morris et al., 2000). Without these cues, the impaired basal ganglia are left to rely on internal cueing mechanisms to scale movements accurately, a circuitry often miscalibrated for individuals with PD. As a result, gait is often small and shuffling in nature, writing is small and difficult to read, and speech production is soft and difficult to hear. Although the internal cueing mechanisms of the basal ganglia are impaired in persons with PD, their ability to make use of external cues is still intact. As a result, when text is provided, it acts as an external model, improving the prosodic quality of speech production.

An alternative explanation is that there are fewer demands on cognitive-linguistic functioning, specifically language formulation, when text is provided. As a result, additional resources may be made available, allowing for more devotion to prosodic functioning. Prior to production, the speech system has the additional cognitive-linguistic processing required for language formulation and phoneme selection (Van Der Merwe, 1997). Thus, it is possible that the text provided enhanced motor planning/programming through a reduction in cognitive load. In other words, when the message is pre-determined by the provided text, frontolimbic circuitry is free to provide more resource support to the development and execution of muscle programs mediated by the basal ganglia (Grybiel, 2000; Turner, 2010). This argument was first put forth by Canter and Van Lancker (1985) to explain why a participant with PD had improved intelligibility while reading versus a spontaneous speech monologue. The researchers attributed the improvements in intelligibility to the text decreasing the cognitive demand of language processing, freeing up resources that enhance speech motor planning/programming resulting in enhanced production. This was also offered as possible reason participants with PD improved speech performance while reading in later studies by Kempler & Van Lancker (2002) and Sidtis

et al., (2012). Although these investigations focused on intelligibility, the same mechanisms are likely at play, with improvements to naturalness directly influencing the accuracy of speech productions (Duffy, 2013). Although a reduction in cognitive load is one explanation for enhanced performance while reading, using this line of reasoning, one would anticipate that both speaking groups would demonstrate improvement. As the groups differed with respect to change in naturalness, this explanation is unlikely.

Another possible reason for the increase in PD naturalness scores in the reading condition may be the result of increased attentional focus to the task of speaking. Externally cued tasks, by their very nature, often heighten a person's awareness and attention to the task at hand. In fact, external factors such as use of speech materials, physical setting, and/or motivation have been shown to increase typical speaker's attention to their speech production, enhancing performance (Goberman & Elmer, 2005; Hustad & Weismer, 2007; Kent et al., 1989). The same enhancements have been found in individuals with PD (Keintz et al., 2007; Neelly, 1956; Sarno, 1968; Weismer, 1984). Thus, it is possible that the participants with PD were able to focus their attention and increase effort towards speech production, which helped to enhance their naturalness while reading. Yet, as was the case with reduced cognitive load, using this line of reasoning, one would anticipate both speaker groups to improve in the reading condition. Therefore, increased attentional focus was unlikely the reason for improvement.

Unlike participants with PD, the cerebellar group did not differ in their perceived naturalness between reading and covert speech. The reason for this finding is most likely related to the nature of the disordered cerebellum. The cerebellum is believed to play a prominent role in externally cued movements (Jueptner & Weiller, 1998; Van Donkelaar et al.,

1999, 2000). While both the basal ganglia and cerebellum are concerned with motor performance, the cerebellum is preferentially involved in monitoring the outcome of movements by comparing with sensory inputs (Jueptner & Weiller, 1998). When impaired, it is less likely that the cerebellum would be able to utilize external cues to recognize and make the adjustments needed to improve the subtle nuances involved in the prosodic features of connected speech. Whereas for those with PD, the ability to benefit from external cueing and incoming sensory stimuli is still intact, allowing for prosodic alteration.

Unlike the basal ganglia, impairment to the cerebellum is not simply a miscalibration of scaled movements; the entire system itself is disrupted. Therefore, it is possible that the cerebellum is limited in its ability to make use of external cues to compensate and/or bypass impairment, regardless of task. Meanwhile, participants with PD are able to use the cues provided by written text in conjunction with sensory feedback to make the needed prosodic adjustments that resulted in improved perceived naturalness by the experienced listeners. Hence, for participants with CD, placing more effort into improving speech productions as a result of reduced cognitive load and/or directed attentional focus is less likely to result in an improvement to perceived changes to intonation patterns, speech rhythm, inflection, and/or vocal intensity.

Another difference noted between the two speaker groups was rate of speech during the two tasks. On average, conversational speech is faster than oral reading in healthy, adult speakers (Hasbrouck & Tindal, 2006). To assess for these differences, paired-t tests were completed comparing conversation and reading rates per sample, per speaker group (see Table 9). Results revealed that participants with PD were significantly faster during the reading task

compared to covert conversation. Conversely, participants with CD were significantly slower when reading versus their conversational speech rate. Thus it is possible that a slower rate of speaking during the reading task accentuated the placement of equal and excessive stress on spoken syllables common in ataxia (Duffy, 2013). As a result, participants with CD were not perceived to improve their naturalness while reading.

Perceptual Ratings of Understandability

In the current study, understandability was defined for our experienced listeners as “the speaker’s articulatory precision”. Results revealed a significant improvement in understandability for the reading task compared to the covert conversation for *both* speaker groups (see Figures 2 and 3). This outcome was unexpected and contrary to our predictions. The most likely reason(s) for these improvements are attributed to the nature of the task, reduced cognitive load, and/or increased attentional focus.

Before discussing these possible reasons, it is important to consider one design element that differed in the current experiment compared to earlier studies by Canter and Van Lancker (1985), Kempler and Van Lancker (2002), and Sidtis et al., (2012). In these investigations, written transcription of speech production was used to obtain intelligibility scores versus perceptual ratings in the current study. Intelligibility, which gives a percentage of words accurately transcribed, can be relatively preserved in some individuals with PD (Duffy, 2013). For this reason, we chose to use perceived “understandability” versus “intelligibility” to capture additional elements (i.e., distinguishability between words) of the speaker’s productions. When defining understandability, one will find definitions vary depending on the reference used. Bloch and Wilkinson (2004, 2009) define understandability as being “distinct from intelligibility”

as “something that happens in conversation”. Yorkston and colleagues (1999) define understandability as “the extent to which you understand the speaker”. Since we were not interested in getting a word for word percentage of correctness, we defined understandability as “the speaker’s articulatory precision”. It was explained to the listeners that understandability was being used as a perceptual judgment of the extent to which each spoken word was distinguishable from the next and the speaker’s articulation was precise. It was further explained that we wanted to make sure to capture articulatory accuracy given that a speaker can be 100% understandable while their articulatory precision is impaired. In making their ratings, listeners were told to use their best clinical judgment. The use of this explanation seems to have helped avoid a skewing effect in which scores gravitated towards 100% understandable. Considering this, along with good intra- and inter-rater reliability, it appears listeners accounted for articulatory precision as well as distinguishability of each spoken word while making their judgments.

For both naturalness and understandability, our predictions of improvement in the PD group were supported by the results. Yet, as mentioned above, our secondary hypothesis – that the PD and CD groups would have different improvement patterns – was not supported for the understandability measure. During the reading task, participants with CD performed similar to the PD group, demonstrating statistically significant improvement in understandability. One reason both impairment groups benefited may be related to the nature of the task itself. The act of taking a breath in and reading a sentence establishes a more stable platform upon which to build a more understandable utterance than speaking spontaneously (Duffy, 2013). One of the main treatment approaches for clients with dysarthria is to take a breath in prior to

speaking in order to ready the system for speech production. Doing so aids in establishing a more controlled breath flow that helps to decrease excessive loudness variations and improves coordination of breath control patterns (Duffy, 2013; Yorkston et al., 1999). It appears then that the very nature of the reading task, which readied the system for speech, was perhaps enough to boost the performance of both individuals with PD and CD to the point of significant improvements for perceived understandability.

An additional consideration that may have resulted in experienced listeners rating both groups higher on understandability during the reading task may be related to the need for less cognitive/linguistic processing. Similar to reasons discussed earlier for improved naturalness in PD, reading may have helped free up more cognitive resources. Reduced cognitive load has been shown to improve speech intelligibility in participants with PD by Bunton and colleagues (2008) in their single versus dual task paradigm discussed earlier. Intelligibility scores for reading significantly improved from 78.28% in the dual task condition to 90.2% in the single task condition, which the authors attributed to less cognitive load. It is thought that reading, as opposed to spontaneous speech, provides an external template or cue for speech production which may reduce the demand on internal cerebral resources for the motor behavior (Kempler & Lancker, 2002). Thus, the reading task in the current experiment allowed for more cognitive resources to be allocated to the mechanics of speech production. In the conversational, covert speech task, additional higher up processing had to occur prior to speech production, placing a greater demand on resource allocation (Van der Merwe, 1997; Guenther et al., 2007; 2009; 2012). Thus, it is feasible that the result of a lessened cognitive load would lead to improved understandability during the reading task for both impairment groups (Kempler et al., 2002).

Another possibility for an enhancement in perceived understandability in both groups may lie in the increase of attentional focus during performance of the reading task. As discussed earlier, the presence of recording and other testing equipment may change the execution of the task, inadvertently improving performance in production of individual phonemes, and/or increased amplitude of the speech signal (Aronson, 1990). Thus, it is possible that the knowledge of being recorded, physical setting, and/or motivation may have directed additional attentional focus of participants to their speech production. As a result, the mechanics of speech productions were such that a noticeable improvement was perceived during the reading task for both speaker groups (Hustad & Weismer, 2007).

Results of our investigation lend support to previous studies suggesting individuals with PD have enhanced understandability/articulatory precision, when reading (Canter & Van Lancker, 1985; Kempler & Van Lancker, 2002; Sidtis et al., 2012). Both Canter and Van Lancker (1985) and Kempler and Van Lancker (2002) found statistically significant improvement to intelligibility while reading versus spontaneous speech in participants with PD. Although significant differences were not found by Sidtis and colleagues (2012), a pronounced trend indicated intelligibility was enhanced while reading. The authors attributed the lack of significant findings to the mild level of speech impairment amongst participants. In the current study for our participants with PD, we had a range of severity levels for understandability, 40% mild, 40% moderate, and 20% severe. Although our participants with PD may have had some benefit from external cueing provided in the written text, the fact that the cerebellar group performed just as well makes this less likely.

Not all studies, however, have found improved intelligibility while reading. For example, Tjaden and Wilding (2011) found no significant differences, using scaled estimates, between spontaneous monologue and reading in participants with PD ranging in severity level from mild to severe. Yet in their study, listeners were college students, not experienced listeners, who found the use of direct magnitude scaling (DME) confusing. As a result, intra- and inter-rater reliability was weak, bringing the outcomes into question. Bunton and colleagues (2008) also found non-significant differences between speech elicited by a spontaneous monologue and sentence reading in the single task portion of their dual task experiment. The authors cautioned, however, about the interpretation of this result in relation to previous speech task studies, given that their experimental design was for exploring dual task paradigms and may not be directly comparable.

In sum, it appears perceived naturalness may have been better at identifying the benefit of external cues to speech production in persons with PD than did understandability. It is possible that the Parkinson's group may have been more adept in making use of these cues and incoming sensory information to generate the needed adjustments to prosody that the cerebellar group was unable to utilize. Experienced listeners perceived understandability significantly better during the reading task for both impairment groups. Thus, it appears the nature of the reading task, reduced cognitive/linguistic load, and/or increased attentional focus played a role in improved understandability for both impairment groups. Although it is possible that participants with PD had enhanced understandability while reading due to external cues, we are unable to determine this given the significant findings for both groups. Still, results

showing improved naturalness while reading appear to suggest that participants with PD can use external cues in the form of written text to enhance naturalness of speech productions.

Individual Performance Patterns and Gender Differences

In addition to the overall analysis, we also considered individual performance patterns and trends. To identify the speakers who had the most perceived change between speaking tasks, a conservative method was undertaken in which differences between speaking tasks were required to be greater than 1 SD from the average difference of the group as a whole (Spencer et al., 2009). In general, eight speakers (80%) with PD had more than a 5 point increase in naturalness while reading compared to no participants in the cerebellar group. From this 80%, two of the participants with PD had pronounced (greater than 1 SD) improvement in naturalness when reading. Participant PD 7, who was determined to have severe hypokinetic dysarthria for the dimension of naturalness, saw the greatest improvement of 35.7 points. With the exception of PD5, all participants with PD demonstrated greater than a 0.6 point improvement (range 0.6 – 35.7) in naturalness during the reading task.

With respect to understandability, seven speakers (70%) with PD had more than a 5 point increase in understandability while reading compared to two participants (33%) with CD. From these participants, one individual, PD7, who was determined to have severely impaired understandability, demonstrated greater than a 2 SD (53.4 points) improvement in perceived understandability. For the cerebellar group, two participants with CD met the established criteria of 1 SD. Overall, both speaker groups demonstrated a 0.5 point improvement or greater (PD range 0.5 – 53.4; CD range 1.1 – 9.7) during the reading task. In general, when considering individual performance levels per speaker group for both perceptual dimensions, participants

with PD had greater point increases than did those with CD. Thus, experienced listeners were better able to detect enhanced naturalness and understandability in individuals with PD during the reading condition.

Gender differences in hypokinetic speakers have been documented in the past with respect to prosody (Boutsen et al., 2010; Kent & Kim, 2003; MacPherson et al., 2011). Given our PD group was predominately males, it was important to consider whether gender differences may have contributed to our results. MacPherson and colleagues (2011) found women with PD produced greater F0 SD and pitch range in semitones than did men with PD and women without PD. Men with PD produced lower pitch range in semitones than did men without. These findings are similar to previous studies that show a gender difference in female intonation patterns for persons with PD (Doyle et al., 1995; Hertrich & Ackermann, 1995; Holmes et al., 2000; Scott et al., 2000). In the present study, there was only one female speaker with PD and nine male speakers. Given that women have more varied prosody, one might anticipate that a speaking group of predominantly women might inherently perform better in the naturalness task than a group of predominantly men. Yet, in the present study, we found a significant improvement in perceived naturalness despite the fact that the group was comprised of predominantly men.

Clinical Implications

Results of this study highlight the importance of not relying too heavily on single measures of speech performance to make theoretical and/or clinical judgments regarding the nature and severity of dysarthria. Doing so can limit the true extent of findings. The motor speech system, including the planning, programming, and execution of articulatory movements,

is complex. As such, in the current investigation, if only understandability or intelligibility was selected to measure differences between speech production in participants with PD and CD, we would have concluded that both speaker groups performed similarly. By including naturalness, an additional measure of perceptual speech, we were able to identify group differences that provided additional insight into the complex nature of the speech motor system.

Clinicians should be mindful of the impact external cues have on speech production and how their use during testing can paint an unrealistic picture of true day-to-day performance. Historically, clinicians have placed much emphasis on the importance of intelligibility levels to diagnose and manage dysarthria. However, relying solely on intelligibility testing that uses reading stimuli may be too limiting. In the current investigation, for example, PD2 had a 97% intelligibility rating on the sentence portion (reading) of the SIT, with a perceptual rating of mild for both understandability and naturalness. Yet, participant PD3 scored just one point less at 96% and was rated with moderately impaired understandability and naturalness. PD1 also scored a 96% with a communication ratio of 1, interpreted as intelligibility being comparable to that of a healthy adult speaker. Yet both expert listeners rated him as moderately dysarthric for perceived understandability and naturalness. In fact, his conversational speech was riddled with disfluencies, far from that which would be expected to occur naturally in day-to-day discourse with a healthy adult speaker. Clearly, differential diagnosis of severity levels using a standardized measure of intelligibility and/or reading passage does not provide a comprehensive representation of a speaker's true depth of impairment, and may actually overinflate true abilities. The impact of such a misjudgment may result in setting inappropriate goal levels and/or limited therapy time authorized by a physician and/or insurance provider.

Thus, it is crucial that the evaluation process include a spontaneous speech sample to gain additional insight into the true level and nature of impairment.

Another important speech characteristics clinicians should keep in mind is naturalness. From the results discussed earlier, it is clear that naturalness plays a fundamental role in the unique speech characteristics found in individuals with hypokinetic dysarthria. Experienced listeners were better able to identify and rate the subtle nuances present in the disordered speech samples that understandability was unable to capture. Understandability considers mechanical elements of speech production such as respiration, phonation, articulation, and resonance. Naturalness, on the other hand, takes into consideration additional elements of the speech signal, including rate, rhythm, intonation, and intensity; key elements disrupted in hypokinetic dysarthria. In doing so, the rating of naturalness is better able to identify the true depth and severity of speech involvement related to individuals with hypokinetic dysarthria. This can be seen in Table 10 where mean ratings for naturalness are lower than understandability ratings. Thus, it is imperative that naturalness be included in the evaluation process.

In sum, clinicians should avoid using a single measure of speech performance such as intelligibility scores or perceived understandability. Doing so may fail to discover underlying characteristics of the signal that also contribute to the impairment. Clinicians should keep in mind that their patients with PD perform better when external cues (i.e., reading, repeating) are provided. To avoid this and obtain a more realistic picture of their daily speech performance, a spontaneous speech sample is crucial. Finally, best clinical practice should include a measure of naturalness to capture the prosodic abnormalities that are prominent in

hypokinetic speakers (Duffy, 2013). Otherwise, clinicians are doing a disservice to their hypokinetic speakers, misrepresenting their true struggles with daily communication.

Conclusions

This study aimed to examine the effects of speech task on understandability and naturalness in two different clinical populations, individuals with PD and those with CD. Using a visual analogue scale, experienced listeners perceived speakers with PD to be more natural during a reading task versus conversational speech. Conversely, no perceived differences in naturalness were seen for the ataxic speakers. One possible reason for this result stems from the limb motor literature suggesting participants with PD perform motor tasks better when provided external cues. The reading condition may have provided the external cueing necessary to boost the PD group's perceived naturalness scores to significant levels. For understandability, the speech of participants with PD and CD was rated significantly higher during the reading condition, believed to be the result of task nature, attentional focus, and/or reduced cognitive load. It appears then, that naturalness may be playing a more prominent role and possibly be a better identifier of the benefits external cues provide people with PD. In any case, using a single measure to identify group differences is problematic. The prosodic characteristics captured in the rating of naturalness, (i.e., rate, rhythm, intonation patterns, and volume) add additional elements of the message that understandability rating/testing may be overlooking. Additionally, these elements appear to be key players in the disordered motor speech productions found in persons with PD. Overall, outcomes of this study revealed the importance of including additional impairment groups and measurements in the study of speech processes in PD. Also, results demonstrate the importance of including measures of

naturalness and spontaneous speech samples during the clinical assessment of dysarthric speech. Relying too heavily on standardized testing can be misleading. Additional research is needed to better understand the similarities and differences in provision of external cues (reading and/or repeating) to those with PD and those with other disorders impacting motor speech systems.

Limitations

The main limitation of the current investigation is the small and unequal sample size. As is the case with many studies of impaired populations, the small number of participants can make interpretation of results less straight forward. This is especially true for the cerebellar group who had only six participants compared to the Parkinson's group with ten. Having additional ataxic speakers would have made for a more equitable comparison between groups and possibly resulted in increased differentiation between tasks. Future investigations should take recruiting efforts and participant pool in mind, allowing enough time to obtain as many participants as possible.

Although both groups had a range of severity, the cerebellar group lacked a participant with a moderate severity level for understandability and a severely impaired individual for naturalness. Although recruitment efforts focused on getting a varied sampling of severity levels, simply getting ataxic speakers was a challenge. In addition to recruiting more participants, future studies should continue striving for a range of severity levels.

Lastly, our study relied on perceived ratings of performance, which in themselves are inherently subjective. This was necessary, however, given that we were interested in how experienced listeners/Speech-Language Pathologist use their best tool, hearing, to perceptually

rate speech production of hypokinetic and ataxic speakers. Speech-Language Pathologists rely heavily on how a speaker sounds to make their best clinical judgment as to impairment type and severity level. Although perceptual ratings run the risk of being affected by unusual rater biases, misinterpretation of directions, etc., our reliability within and between raters was good, failing to substantiate this possibility. Still, future studies may want to consider increasing the number of listeners and/or adding additional measures, such as acoustic analysis, in addition to perceptual ratings.

Future Directions

Future research is needed to better understand how the use of external cueing influences speech production in participants with PD. Acoustic measures of speech production comparing understandability and naturalness in conversational speech, reading, and/or repeating would lend additional insights to the growing body of literature exploring task based speech differences in PD. In light of the differences found between hypokinetic and ataxic speakers in the current investigation, future studies should include a clinical comparison group such as cerebellar disease and/or other clinical populations. The current investigation also highlights the importance of using naturalness and a spontaneous speech sample in the assessment process. Though, at present, there are no professionally agreed upon or standardized ways of judging understandability and naturalness of a patient's conversational speech. Thus, future research should explore ways of standardizing the rating of speech characteristics during a spontaneous speech sample and/or establishing a consistent means by which clinicians can perceptually rate severity levels of their patients. Improved knowledge in

these areas will help speech researchers to better understand external cueing in PD and clinicians to provide better service and education to their patients and families.

Appendix A

Extraction Criteria

1. No proper nouns
 - a. No words that start with a capital letter (i.e., names of people, places, cities, states, countries)
2. No low frequency words
 - a. Leave out words that are not commonly used, higher level vocabulary words. (i.e., "The sky looks ominous." "It looks like we might get a deluge of rain.")
3. No formulaic expressions (i.e., "Just in the nick of time")
4. No specialty vocabulary
5. Contains 5-15 words in the sentence.
6. OK to take part of a run-on sentence that's joined by a conjunction or filler word. Make sure the speaker is done with that part of the utterance and you can indeed clip it and it would stand alone as a full and complete sentence.
7. Don't include sentences that contain filler words (in the middle) or slang, (i.e., "gonna"). You can use a sentence if the filler word was located at the beginning or end. Make sure when cutting it out that the rest of the sentence can stand alone as a complete sentence.
8. Do not take a sentence that has marked personal emotion (i.e., laughing, over exaggeration that is not natural, etc.).
11. OK to include numbers.
12. Words can be used if understandable given context.
13. If a word is unintelligible within a sentence that meets criteria, verify word with speaker.
14. Do not include a sentence with word revisions.
15. Take the very first 5 sentences that meet criteria, followed by the next three that meet criteria as back-ups.

APPENDIX B

Software Programming

The MATLAB application for the listener's rating procedure used a GUI layout that included the two slider bars/VAS, "PLAY, NEXT, and SAVE" buttons, file counter, and a "Participant ID" editable text field. When the application was launched, the GUI window appeared and the initialization script was executed automatically, importing the speaker's wave files, creating a file list and arming the shuffle function on the "PLAY" button. Pressing "PLAY" would select and play a random sound file from the complete list of speaker files. The clip's file ID would then be indexed, and the flag set to "1". The listener would then evaluate the speaker's speech for naturalness and understandability. Because the flag was set to "1", the shuffle function was disabled for any consecutive pressing of "PLAY". Once the participant was done evaluating the file, he/she pressed "NEXT", which recorded and saved the Participant ID, File ID, Understandability score, and Naturalness score respectively, as a row in a MATLAB array designated as DATA. To prevent repetition of the same clip, the file index of the evaluated sound file was used to delete the file ID from the complete list. The counter value in the top center of the screen was then increased by one, allowing the listener and experimenter to keep track of files played and rated; the flag was then set back to "0". The "NEXT" button was programmed to disable itself until the "PLAY" button was pressed, which set the flag back to "1". Any subsequent consecutive presses of "NEXT" resulted in a system error sound being played, and no other action being taken until the next file was played. This process was repeated by the listener until all of the sound files were played in a random order and rated. When the file list became empty, the "NEXT" button changed to read "END", at which point it

automatically saved all of the data as OUTPUT.xls, into the MATLAB home directory. The data could then be opened from Excel with the rows corresponding to: [Participant ID] [File ID] [Understandability (0-100)] [Naturalness (0-100)]. In addition, if the experiment needed to be terminated prematurely or paused, the top right "SAVE NOW" button could be clicked, which generated an Excel file of all data recorded up to that point. Pressing "SAVE NOW" would not terminate the experiment and could be continued if needed. Additionally, "SAVE NOW" could be pressed whenever the experimenter wished to create a checkpoint to save a backup of all of the data up to that point. If so, it would overwrite earlier output files in the home directory. After "SAVE NOW" is pressed, or the bottom right button turns to read "END", the program could be exited safely with all data saved.

Appendix C

Directions

“During the experiment you will see the screen currently displayed on the monitor (Figure 1). The screen will remain consistent throughout the entire experiment. To play a sound clip, click once on the “PLAY” button. The sound clip will play only once. You are not able to repeat the clip or adjust the volume. Be aware that the sentences are anywhere from 5-15 words. Short sentences may seem to go by very quickly, so be ready. After hearing the entire sound clip, use your best clinical judgment to rate the speaker on how “Understandable” and how “Natural” they sounded. For “Understandability” we defined it as, “the speaker’s articulatory precision”. Understandability was used versus intelligibility given that the researchers are not seeking an actual word for word percentage of correctness. Instead, understandability is being used as a perceptual judgment of the extent to which each spoken word is distinguishable from the next and their articulation is precise. We want to make sure to capture the articulation accuracy of the production; because someone can be 100% understandable while their articulation is very poor. So rate on how well you understand each spoken word, while keeping articulatory precision in mind. When you’re ready to rate, using your mouse, slide the cursor along the scale from 0-100, “0” being “unable to understand” and “100” being “completely understandable”. Stop the cursor at the number score you wish to assign to the speaker’s sample. Next, you will have to rate how “Natural” the speaker sounded. “Naturalness” is defined as “the speaker’s prosody – defined as speech rate, rhythm, intonation, stress patterns, and loudness”. When rating “Naturalness”, slide the cursor along the scale from “0-100”, “0” being “highly unnatural” and “100” being “completely natural”, stopping at the number score you wish to assign to the sound clip. Keep in mind that it’s possible to have someone with good “Understandability” while having poor “Naturalness” or vice-versa. After rating both “Understandability” and “Naturalness”, click once on the “NEXT” button and then once on the “PLAY” button to play the next sound clip. Again, you will hear the sound clip one time; rate both “Understandability” and “Naturalness”, click once on “NEXT” then once on “PLAY” etc. There is no need to re-set the scale between ratings. You will be following this same sequence/procedure throughout the entire experiment. At the top right corner of the screen you will notice a button that says “SAVE NOW”. You do not have to worry about this button; it is only for the examiner’s use to save the data if needed in the case of a program error that requires a restart or if you need a break and the examiner wants to save a back-up of your data”.

STEPS TO FOLLOW:

- To begin the experiment, click once on “**PLAY**”. This will play a sound clip one time.
- After hearing the clip, **RATE** the speech sample on “Understandability” and “Naturalness” per the definitions provided. Remember, even though a sample may be completely understandable, pay attention to the articulatory precision and include it in your rating as well.
- Once you have finished rating the sample, click one time on “**NEXT**”.
- Then click one time on “**PLAY**” to play the next clip, rate the sample, and so forth.
- So remember:

CLICK ONCE

PLAY RATE NEXT PLAY

References

- Abbruzzese, G., & Berardelli, A. (2003). Sensorimotor integration in movement disorders. *Movement Disorders*, 18(3), 231-240.
- 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, 165–172.
- Ackermann, H., & Riecker, A. (2004). The contribution of the insula to motor aspects of speech production: A review and a hypothesis. *Brain and Language*, 89, 320–328.
- Alexander, G. E., & Crutcher, M. D. (1990). Functional architecture of basal ganglia circuits: Neural substrates of parallel processing. *Trends in Neurosciences*, 3, 266–271.
- Alexander, G.E., DeLong, M.R., & Strick, P.L. (1986). Parallel organization of functionally segregated circuits linking basal ganglia and cortex. *Annual Review of Neuroscience*, 9, 357-358.
- Alvarez, JA, Emory, E. Executive Function and the Frontal Lobes: A Meta-Analytic Review. (2006). *Neuropsychology Review*, 16 (1), 17-42.
- Azulay, J.-P., Mesure, S., Amblard, B., Blin, O., Sangla, I., & Pouget, J. (1999). Visual control of locomotion in Parkinson's disease. *Brain*, 122(1), 111-120.
- Azulay, J. P., Van Den Brand, C., Mestre, D., Blin, O., Sangla, I., Pouget, J., & Serratrice, G. (1996). [Automatic motion analysis of gait in patients with Parkinson disease: effects of levodopa and visual stimulations]. *Revue neurologique*, 152(2), 128-134.
- Bagley, S., Kelly, B., Tunnicliffe, N., Turnbull, G. I., & Walker, J. M. (June 10, 1991). The Effect of Visual Cues on the Gait of Independently Mobile Parkinson's Disease Patients. *Physiotherapy*, 77, 6, 415-420.
- Baker, K., Rochester, L., & Nieuwboer, A. (December 01, 2007). The Immediate Effect of Attentional, Auditory, and a Combined Cue Strategy on Gait During Single and Dual Tasks in Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation*, 88, 12, 1593-1600.
- Ballanger, B., Thobois, S., Baraduc, P., Turner, R.S., Broussolle, & Desmurget, M. (2006) "Paradoxical kinesis" is not a hallmark of Parkinson's disease but a general property of the motor system. *Movement Disorders*, 21 (9), 1490-1495.
- Beck, A.T., Steer, R.G., & Brown, G.K. (1996). Beck Depression Inventory-II. San Antonio: The Psychological Corporation.
- Behrman, A. L., Teitelbaum, P., & Cauraugh, J. H. (1998). Verbal instructional sets to normalise the temporal and spatial gait variables in Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, 65(4), 580-582.

- Benecke R., Rothwell, J.C., Dick, J.P.R., Day, B.L., & Marsden, C.D. (1986). Performance of simultaneous movements in patients with Parkinson's disease. *Brain*, 109, 739-757.
- Benecke, R., Rothwell, J.C., Dick, J.P.R., Day, B.L., & Marsden, C.D. (1987). Disturbance of sequential movements in patients with Parkinson's disease. *Brain*, 110, 361-379.
- Benton, A., de S Hamsher, K., Varney, N., & Spreen, O. (1983). Contributions to neuropsychological assessment- A clinical manual. New York: Oxford University Press.
- Berardelli, A., Rothwell, J.C., Thompson, P.D., & Hallett, M. (2001). Pathophysiology of bradykinesia in Parkinson's disease. *Brain*, 124, 2131-2146.
- Berger, H.J.C., van Es, N., van Spaendonck, K.P.M., Teunisse, J., Horstink, M.W.I.M., van't Hof, M.A., & Cools, A.R. (1999). Relationship between memory strategies and motor symptoms in Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology*, 21(5), 677-684.
- Blanchet, P., & Snyder, G. (2010). Speech rate treatments for individuals with dysarthria: a tutorial. *Perceptual and Motor Skills*, 2010, 110, 3. 965-982.
- Bohland, J. W., Bullock, D., & Guenther, F. H. (January 01, 2010). Neural representations and mechanisms for the performance of simple speech sequences. *Journal of Cognitive Neuroscience*, 22, 7, 1504-29.
- Bridges, K., Van Lancker Sidtis., D., & Sidtis, J. (2012). The role of the basal ganglia on production of r ecited speech: Effects of Parkinson's disease and DBS therapy.
- Brotchie P, Iansek, R., & Horne, M.K. (1991a). Motor function of the monkey globus pallidus: 1. Neuronal discharge and parameters of movement. *Brain*, 114, 1667-1683.
- Brotchie P, Iansek, R., & Horne, M.K. (1991b). Motor function of the monkey globus pallidus: 2. Cognitive aspects of movement and phasic neuronal activity. *Brain*, 114, 1685-1702.
- Brotchie P, Iansek, R., & Horne, M.K. (1991c). Neural network model of neural activity in the monkey globus pallidus. *Neuroscience Letters*, 131, 33-36.
- Bunton, K. & Keintz, C. (2008). The use of a dual-task paradigm for assessing speech intelligibility for clients with Parkinson disease. *Journal of Medical Speech-Language Pathology*, 16, 141-155.
- Bunton, K., Kent, R., Kent, J., & Rosenbek, J. (2000). Perceptuo-acoustic assessment of prosodic impairment in dysarthria. *Clinical Linguistics & Phonetics*, 2000, 14, 1, 13-24.
- Burleigh-Jacobs, A., Horak, F. B., Nutt, J. G., & Obeso, J. A. (January 01, 1997). Step initiation in Parkinson's disease: influence of levodopa and external sensory triggers. *Movement Disorders : Official Journal of the Movement Disorder Society*, 12, 2, 206-15
- Canavan, A.G.M., Passingham, R.E., Marsden, C.D., Quinn, N., Wyke, M., & Polkey, C.E. (1989). The performance on learning tasks of patients in the early stages of Parkinson's disease. *Neuropsychologia*, 27(2), 141-156.

- Cannito, M. P., & Marquardt, T. P. (1997). Ataxic dysarthria. *Clinical management of sensorimotor speech disorders*, 217-247.
- Canter, G. J. & Van Lancker, D. (1985). Disturbances of the temporal organization of speech following bilateral thalamic surgery in a patient with Parkinson's disease. *Journal of Communication Disorders*, 18, 329-349.
- Cooper, J.A., Sagar, H.J., Jordan, N., Harvey, N.S., & Sullivan, E.V. (1991) Cognitive impairment in early, untreated Parkinson's disease and its relationship to motor disability. *Brain*, 114, 2095-2122.
- Cortina, J. (1993). What is coefficient alpha? An examination of theory and applicaitons. *Journal of Applied Psychology*. 78, 1, 98-104.
- Cubo, E., Leurgans, S., & Goetz, C. G. (2004). Short-term and practice effects of metronome pacing in Parkinson's disease patients with gait freezing while in the 'on'state: randomized single blind evaluation. *Parkinsonism & related disorders*, 10(8), 507-510.
- Cunnington, R., Iansek, R., Bradshaw, J. L., & Phillips, J. G. (1995). Movement-related potentials in Parkinson's disease Presence and predictability of temporal and spatial cues. *Brain*, 118(4), 935-950.
- Cunnington, R., Iansek, R., Bradshaw, J.L., & Phillips, J.G. (1996). Movement related potentials associated with movement preparation and motor imagery. *Experimental Brain Research*, 111, 429-436.
- Cunnington, R., Iansek, R., & Bradshaw, J. L. (1999). Movement-related potentials in Parkinson's disease: External cues and attentional strategies. *Movement Disorders*, 14(1), 63-68.
- Currà, A., Berardelli, A., Agostino, R., Modugno, N., Puorger, C. C., Accornero, N., & Manfredi, M. (1997). Performance of sequential arm movements with and without advance knowledge of motor pathways in Parkinson's disease. *Movement Disorders*, 12(5), 646-654.
- Daneman M., & Carpenter P.A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 19, 450-66.
- Darley, F.L., Aronson, A.E., & Brown, J.R. (1975). *Motor speech disorders*. Philadelphia: Saunders.
- De Krom, G. (1994). Consistency and reliability of voice quality ratings for different types of speech fragments. *Journal of Speech and Hearing Research*, 37, 985-1000.
- Defer, G.L., Widner, H., Marie, R.M., Remy, P., & Levivier, M. (1999). Core assessment program for surgical interventional therapies in Parkinson's disease (CAPSIT-PD). *Movement Disorders*, 14, 572- 584.
- Delis, D.C., Kramer, J.H., Kaplan, E., & Ober, B.A. 1987. *California verbal learning test*. New York: The Psychological Corporation.
- Della Sala, S., Gray, C., Baddeley, A., & Wilson, L. (1997). *The Visual patterns Test: A new test of short term visual recall*. Feltham, Suffolk: Thames Valley Test Company.

- DeLong, M.R. (2000). The basal ganglia. In E.R. Kandel, J.H. Schwartz, & T.M. Jessell (Eds.), *Principles of neural science* (4th ed., pp. 853-867). New York: McGraw-Hill.
- Dibble, L. E., & Nicholson, D. E. (January 01, 1997). Sensory Cueing Improves Motor Performance and Rehabilitation in Persons with Parkinson's Disease. *Neurology Report*, 21, 4, 117-124.
- Diener, H. C., & Dichgans, J. (1992). Pathophysiology of cerebellar ataxia. *Movement Disorders*, 7(2), 95-109.
- Dromey, C. (2003). Spectral measures and perceptual ratings of hypokinetic dysarthria. *Journal of Medical Speech-Language Pathology*, 11(2), 85-94.
- Duffy, J. R. (2013). *Motor speech disorders: substrates, differential diagnosis, and management*. St. Louis, MO: Elsevier Mosby.
- Eadie, T.L., & Baylor, C.R. (2006). The effect of perceptual training on inexperienced listeners' judgements of dysphonic voice. *Journal of Voice*, 20, 527-545.
- Eni, G. O. (1988). Gait improvement in parkinsonism: the use of rhythmic music. *International Journal of Rehabilitation Research*, 11(3), 272-274.
- Engen, T. (1971). Psychophysics: II. Scaling methods. In J. W. Kling & L. A. Riggs (Eds.), *Woodworth & Schlosberg's experimental psychology: Third Edition* (pp. 47-86). New York: Holt, Rinehart and Winston Inc.
- Enzensberger, W., & Fischer, P. A. (January 01, 1996). Metronome in Parkinson's disease. *Lancet*, 347, 9011.)
- Evarts, E. V., & Wise, S. P. (1984). *Basal ganglia outputs and motor control*. Paper presented at the Ciba Foundation Symposium 107-Functions of the Basal Ganglia.
- Ferrandez, A.-M., Hugueville, L., Lehericy, S., Poline, J.-B., Marsault, C., & Pouthas, V. (2003). Basal ganglia and supplementary motor area subserve duration perception: an fMRI study. *Neuroimage*, 19(4), 1532-1544.
- Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). Mini-mental state. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12, 189-198.
- Fox, C., Morrison, C., Ramig, L., & Spair, S. (2002). Current perspectives on the Lee Silverman Voice Treatment (LSVT). *Journal of Neurology, Neurosurgery, and Psychiatry*, 48, 517-529.
- Freedland, R. L., Festa, C., Sealy, M., McBean, A., Elghazaly, P., Capan, A., Brozycki, L., ... Rothman, J. (January 01, 2002). The effects of pulsed auditory stimulation on various gait measurements in persons with Parkinson's Disease. *Neurorehabilitation*, 17, 1, 81-7.
- Freedman, S. E., Maas, E., Caligiuri, M. P., Wulf, G., & Robin, D. A. (January 01, 2007). Internal versus external: oral-motor performance as a function of attentional focus. *Journal of Speech, Language, and Hearing Research : Jslhr*, 50, 1, 131-6.

- Freeman, J. S., Cody, F. W., & Schady, W. (January 01, 1993). The influence of external timing cues upon the rhythm of voluntary movements in Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry*, 56, 10, 1078-84.
- Galletly, R., & Brauer, S. G. (January 01, 2005). Does the type of concurrent task affect preferred and cued gait in people with Parkinson's disease?. *Australian Journal of Physiotherapy*, 51, 3, 175-180.
- Georgiou, N., Iansek, R., Bradshaw, J.L., Phillips, J.G., Mattingley, J.B., & Bradshaw, J.A. (1993) An evaluation of the role of internal cues in the pathogenesis of parkinsonian hypokinesia. *Brain*, 116, 1575-1587.
- Georgiou, N., Bradshaw, J. L., Iansek, R., Phillips, J. G., Mattingley, J., & Bradshaw, J. (1994). Reduction in external cues and movement sequencing in Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, 57(3), 368-370.
- Gerratt B.R., Kreiman, J., Antonanzas-Barroso, N., & Berke, G.S. (1993). Comparing internal and external standards in voice quality judgements. *Journal of Speech and Hearing Research*, 36, 14-20.
- Giladi, N., McMahon, D., Przedborski, S., Flaster, E., Guillory, S., Kostic, V., & Fahn, S. (1992). Motor blocks in Parkinson's disease. *Neurology*, 42(2), 333-333.
- Giladi, N., Treves, T., Simon, E., Shabtai, H., Orlov, Y., Kandinov, B., . . . Korczyn, A. (2001). Freezing of gait in patients with advanced Parkinson's disease. *Journal of neural transmission*, 108(1), 53-61.
- Goberman, A. M., & Elmer, L. W. (2005). Acoustic analysis of clear versus conversational speech in individuals with Parkinson disease. *Journal of Communication Disorders*, 38(3), 215-230.
- Goodglass, H. & Kaplan, E. (1983). Assessment of aphasia and related disorders (2nd ed.). Philadelphia: Lea & Febiger.
- Graybiel, A. M., Canales, J. J., & Capper-Loup, C. (2000). Levodopa-induced dyskinesias and dopamine-dependent stereotypies: a new hypothesis. *Trends in neurosciences*, 23, S71-S77.
- 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. *Neurophysiologia*, 37, 1453-1460.
- Ho, A.K., Iansek, R., & Bradshaw, J.L. (2002). The effect of a concurrent task on parkinsonian speech. *Journal of Clinical and Experimental Neuropsychology*, 24, 36-47.
- Houk, J. C., & Wise, S. P. (1995). Distributed modular architectures linking basal ganglia, cerebellum, and cerebral cortex: Their role in planning and controlling action. *Cerebral Cortex*, 2(Mar/Apr), 95-110.
- Heaton, R.K., Chelune, G.J., Talley, J.L., Kay, G.G., & Curtiss, G. (1993). Wisconsin Card Sorting Test. Odessa, Florida: Psychological Assessment Resources, Inc.

- Hustad, K. (2008). The relationship between listener comprehension and intelligibility scores for speakers with dysarthria. *Journal of Speech, Language and Hearing Research*, 51, 562–573.
- Hustad, K. (2007). Effects of speech stimuli and dysarthria severity on intelligibility scores and listener confidence ratings for speakers with cerebral palsy. *Folia Phoniatrica*, 59, 306–317.
- Ito, M. (2000). Mechanisms of motor learning in the cerebellum. *Brain research*, 886(1), 237-245.
- Ingram, H. A., Van Donkelaar, P., Cole, J., Vercher, J.-L., Gauthier, G. M., & Miall, R. C. (2000). The role of proprioception and attention in a visuomotor adaptation task. *Experimental Brain Research*, 132(1), 114-126.
- Inzelberg, R., Plotnik, M., Flash, T., Schechtman, E., Shahar, I., & Korczyn, A. D. (2001). Mental and motor switching in Parkinson's disease. *Journal of Motor Behavior*, 33(4), 377-385.
- Jahanshahi, M., Jenkins, I. H., Brown, R. G., Marsden, C. D., Passingham, R. E., & Brooks, D. J. (January 01, 1995). Self-initiated versus externally triggered movements. I. An investigation using measurement of regional cerebral blood flow with PET and movement-related potentials in normal and Parkinson's disease subjects. *Brain : a Journal of Neurology*, 118, 913-33.
- Jueptner, M., & Weiller, C. (1998). A review of differences between basal ganglia and cerebellar control of movements as revealed by functional imaging studies. *Brain*, 121, 1437-1449.
- Kalikow, D., Stevens, K. N., & Elliott, L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *The Journal of the Acoustical Society of America*, 61(5), 1337-1351.
- Kay, J. Lesser, R., & Coltheart, M. (1992). *Psycholinguistic Assessment of Language Processing in Aphasia*. Hove, U.K.: Lawrence Erlbaum.
- Keintz, C. K., Bunton, K., & Hoit, J. D. (2007). Influence of visual information on the intelligibility of dysarthric speech. *American Journal of Speech-Language Pathology*, 16(3), 222-234.
- Kelly, V. E., Hyngstrom, A. S., Rundle, M. M., & Bastian, A. J. (January 01, 2002). Interaction of levodopa and cues on voluntary reaching in Parkinson's disease. *Movement Disorders*, 17, 1, 38-44.
- Kempler, D., & Van Lancker, D. (2002). Effect of speech task on intelligibility in dysarthria: a case study of Parkinson's disease. *Brain and Language*, 80, 449-464.
- Kent, R., & Kim, Y. (2003). Toward an acoustic typology of motor speech disorders. *Clinical Linguistics & Phonetics*. 17, 6, 427-445.
- Kent, R.D., Kent, J.F., Weismer, G., & Duffy, J.R. (2000). What dysarthrias can tell us about the neural control of speech. *Journal of Phonetics*, 28, 273-302.
- Kent, R. D., Weismer, G., Kent, J. F., & Rosenbek, J. C. (1989). Toward phonetic intelligibility testing in dysarthria. *Journal of Speech and Hearing Disorders*, 54(4), 482-499.

- Klimkeit, E. I., Bradshaw, J. L., Charlton, J., Stolwyk, R., & Georgiou-Karistianis, N. (2009). Driving ability in Parkinson's disease: current status of research. *Neuroscience & Biobehavioral Reviews*, 33(3), 223-231.
- Knocke, D., Taylor, A.E., & Saint-Cyr, J.A. (1998). The differential effects of cueing on recall in Parkinson's disease and normal subjects. *Brain and Cognition*, 38, 261-274.
- Kreiman J, Gerratt BR, Precoda K, Berke G. (1992). Individual differences in voice quality perception. *Journal of Speech and Hearing Research*; 35, 512-520.
- Kritikos, A., Leahy, C., Bradshaw, J.L., Iansek, R., Phillips, J.G., & Bradshaw, J.A. (1995). Contingent and non-contingent auditory cueing in Parkinson's disease. *Neuropsychologia*, 33 (10), 1193-1203.
- Landis, J.R. & Koch, G.G. (1977). The measurement of observed agreement for categorical data. *Biometrics*, 33, 159-174.
- Levin, B.E., Llabre, M.M., & Weiner, W.J. (1989). Cognitive impairments associated with early Parkinson's disease. *Neurology*, 39, 557-561.
- Lewis, G. N., Byblow, W. D., & Walt, S. E. (September 30, 2000). Stride length regulation in Parkinson's disease: the use of extrinsic, visual cues. *Brain*, 123, 10, 2077.
- Lidsky, T., Manetto, C., & Schneider, J. (1985). A consideration of sensory factors involved in motor functions of the basal ganglia. *Brain Research Reviews*, 9(2), 133-146.
- Lim, I., van Wegen, E., de Goede, C., Deutekom, M., Nieuwboer, A., Willems, A., Jones, D., Rochester, L., & Kwakkel, G. (2005). Effects of external rhythmic cueing on gait in patients with Parkinson's disease: a systematic review. *Clinical Rehabilitation*, 19, 695-713.
- Lings, S., & Dupont, E. (1992). Driving with Parkinson's disease: a controlled laboratory investigation. *Acta neurologica scandinavica*, 86(1), 33-39.
- Luessi, F., Mueller, L., Breimhorst, M., & Vogt, T. (2012). Influence of visual cues on gait in Parkinson's disease during treadmill walking at multiple velocities. *Journal of the neurological sciences*, 314(1), 78-82.
- McGeer, P. L., & McGeer, E. G. (1987). Integration of Motor Functions in the Basal Ganglia *The Basal Ganglia II* (pp. 429-441): Springer.
- MacPherson, M., Huber, J., & Snow, D. (2011). The intonation- syntax interface in the speech of individuals with Parkinson's disease. *Journal of Speech, Language, and Hearing Research*. 54. 19-32.
- Madeley, P., Hulley, J., Wildgust, H., & Mindham, R. (1990). Parkinson's disease and driving ability. *Journal of Neurology, Neurosurgery & Psychiatry*, 53(7), 580-582.
- Marsden, J., & Harris, C. (2011). Cerebellar ataxia: pathophysiology and rehabilitation. *Clinical rehabilitation*, 25(3), 195-216.
- Marsden, C.D. (1982). The mysterious motor function of the basal ganglia: The Robert Wartenberg Lecture. *Neurology*, 32, 514-539.

- Martin, J.P. (1967). The basal ganglia and posture. London: Pitman Medical.
- Martin, K.E., Phillips, J.G., Iansek, R., & Bradshaw, J.L. (1994). Inaccuracy and instability of sequential movements in Parkinson's disease. *Experimental Brain Research*, 102, 131-140.
- Majsak, M.J. (2000). The bradykinesia of patients with Parkinson's disease: an impairment of force output for internally cued movements. *Dissertation Abstracts International: Section B: The Sciences and Engineering*, 61(6-B), 2923.
- Majsak, M.J., Kaminski, T., Gentile, A.M., & Flanagan, J.R. (1998) The reaching movements of patients with Parkinson's disease under self-determined maximal speech and visually cued conditions. *Brain*, 121, 755-766.
- Miller, N. (2013). Measuring up to speech intelligibility. *International Journal Language Communicaiton Disorders*. 48, 6, 601-612.
- Morgan, K. (2008). Dopaminergic medication effects on intelligibility, naturalness, and voice quality in individuals with Parkinson's disease. Unpublished master's thesis, University of Washington, Seattle, Washington.
- Morris, M. E. (2000). Movement disorders in people with Parkinson disease: a model for physical therapy. *Physical therapy*, 80(6), 578-597.
- Morris, M.E., & Iansek, R. (1996). Characteristics of motor disturbance in Parkinson's disease and strategies for movement rehabilitation. *Human Movement Science*, 15, 649-669.
- Morris, M.E., Summers, J.J., Iansek, R., & Matyas, T.A. (1995). Motor control considerations for the rehabilitation of gait in Parkinson's disease. In D. Glencross and J. Piek (Eds.), *Motor control and sensorimotor integration*. Amsterdam: Elsevier Science.
- Munoz, J., Mendoza, E., Fresneda, M.D., Carballo, G., & Ramirez, I. (2002). Perceptual analysis in different voice samples: agreement and reliability. *Perceptual and Motor Skills*, 94, 1187-1195.
- Neely, K. K. (1956). Effect of visual factors on the intelligibility of speech. *The Journal of the Acoustical Society of America*, 28(6), 1275-1277.
- Nelson, H.E. (1976). A modified card sorting test sensitive to frontal lobe defects. *Cortex*, 12, 313-324.
- Nieuwboer, A. (January 01, 2008). Cueing for freezing of gait in patients with Parkinson's disease: A rehabilitation perspective. *Movement Disorders*, 23.
- Nieuwboer, A., Rochester, L., Müncks, L., & Swinnen, S. P. (2009). Motor learning in Parkinson's disease: limitations and potential for rehabilitation. *Parkinsonism & related disorders*, 15, S53-S58.
- Nunnally, J.C. & Bernstein, I.H. (1994). *Psychometric Theory*. New York: McGraw Hill.

- Oliveira, R.M., Gurd, J.M., Nixon, P., Marshall, J.C., & Passingham, R.E. (1997). Micrographia in Parkinson's disease: The effect of providing external cues. *Journal of Neurology, Neurosurgery, and Psychiatry*, 63(4), 429-433.
- Oliveira, R.M., Gurd, J.M., Nixon, P., Marshall, J.C., & Passingham, R.E. (1998). Hypometria in Parkinson's disease: automatic versus controlled processing. *Movement Disorders*, 13, 422-427.
- O'Sullivan, S. B., & Schmitz, T. J. (2007). *Physical rehabilitation*. Philadelphia: F.A. Davis.
- Paolo, A.M., Axelrod, B.N., Tröster, A.I., Blackwell, K.T., & Koller, W.C. (1996). Utility of a Wisconsin Card Sorting Test short form in persons with Alzheimer's and Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology*, 18, 892-897.
- Ramig, L.O., Pawlas, A.A., & Countryman, S. (1995). *The Lee Silverman Voice Treatment*. Iowa City, Iowa: National Center for Voice and Speech.
- Ramig, L.O., Sapir, S., Fox, C., & Countryman, S. (2001). Changes in vocal loudness following intensive voice treatment (LSVT) in individuals with Parkinson's disease: A comparison with untreated patients and normal age-matched controls. *Movement Disorders*, 16, 79-83.
- Reis, J., Giovanni, A., Wuyts, F., & Triglia, J.M. (1999). Comparison of different voice samples for perceptual analysis. *Folia Phoniatrica Et Logopeda*, 51, 108-116.
- Robertson, C., & Flowers, K. (1990). Motor set in Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, 53(7), 583-592.
- Rochester, L., Hetherington, V., Jones, D., Nieuwboer, A., Willems, A.-M., Kwakkel, G., & Van, W. E. (May 01, 2005). The Effect of External Rhythmic Cues (Auditory and Visual) on Walking During a Functional Task in Homes of People With Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation*, 86, 5, 999-1006.
- Romero, D. H., Van Gemmert, A. W. A., Adler, C. H., Bekkering, H., & Stelmach, G. E. (2003). Altered aiming movements in Parkinson's disease patients and elderly adults as a function of delays in movement onset. *Experimental Brain Research*, 151, 249-261.
- Ruff, R.M., Light, R.H., Parker, S.B., & Levin, H.S. (1996) Benton controlled oral word association test: reliability and updated norms. *Archives of Clinical Neuropsychology*, 11(4), 329-338.
- Sailer, A., Molnar, G. F., Paradiso, G., Gunraj, C. A., Lang, A. E., & Chen, R. (2003). Short and long latency afferent inhibition in Parkinson's disease. *Brain*, 126(8), 1883-1894.
- Saint-Cyr, J.A., Taylor, A.E., & Nicholson, K. (1995). Behavior and the basal ganglia. *Advances in Neurology*, 65, 1-28.
- Sarno, M. (1968). Speech impairment in Parkinson's disease. *Archives of physical medicine and rehabilitation*, 49(5), 269-275.

- Sawamoto, N., Honda, M., Hanakawa, T., Fukuyama, H., & Shibasaki, H. (2002). Cognitive Slowing in Parkinson's Disease: A behavioral evaluation independent of motor slowing. *The Journal of Neuroscience*, 22(12), 5198-5203.
- Schell, G.R., & Strick, P.L. (1984). The origin of thalamic inputs to the arcuate premotor and supplementary motor areas. *Journal of Neuroscience*, 4, 539-560.
- Schenk, T., Baur, B., Steude, U., & Bötzel, K. (2003). Effects of deep brain stimulation on prehensile movements in PD patients are less pronounced when external timing cues are provided. *Neuropsychologia*, 41(7), 783-794.
- Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychological bulletin*, 86(2), 420.
- Shumway-Cook, A. & Woollacott, M.H., 2012. *Motor Control: Translating Research into Clinical Practice*. (4th Edition). Philadelphia: Wolters Kluwer Health, Lippincott Williams & Wilkins.
- Sidtis, D., Cameron, K., Bonura, L., & Sidtis, J. J. (March 01, 2012). Speech intelligibility by listening in Parkinson speech with and without deep brain stimulation: Task effects. *Journal of Neurolinguistics*, 25, 2, 121-132.
- Siegert, R.J., Harper, D.N., Cameron, F.B., & Abernethy, D. (2002) Self-initiated versus externally cued reaction times in Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology*. 24 (2), 146-153.
- Spencer, K.A. (2007). Aberrant response preparation in Parkinson's disease. *Journal of Medical Speech-Language Pathology*, 15(1), 83-96.
- Spencer, K. A., Morgan, K. W., & Blond, E. (January 01, 2009). Dopaminergic Medication Effects on the Speech of Individuals with Parkinson's Disease. *Journal of Medical Speech-Language Pathology*, 17, 125-144.
- Stanley, J., Gowen, E., & Miall, R. C. (2007). Effects of agency on movement interference during observation of a moving dot stimulus. *Journal of Experimental Psychology: Human Perception and Performance*, 33(4), 915.
- Stolwyk, R. J., Triggs, T. J., Charlton, J. L., Iansek, R., & Bradshaw, J. L. (2005). Impact of internal versus external cueing on driving performance in people with Parkinson's disease. *Movement Disorders*, 20(7), 846-857.
- Strick, P. L., Dum, R. P., & Mushiake, H. (1995). Basal ganglia 'loops' with the cerebral cortex *Functions of the cortico-basal ganglia loop* (pp. 106-124): Springer.
- Swinnen, S. P. (2002). Intermanual coordination: from behavioural principles to neural-network interactions. *Nature Reviews Neuroscience*, 3(5), 348-359.
- Teasdale, N., Phillips, J., & Stelmach, G.E. (1990) Temporal movement control in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry*. 53, 862-868.

- Teulings, H.-L., Contreras-Vidal, J. L., Stelmach, G. E., & Adler, C. H. (1997). Parkinsonism reduces coordination of fingers, wrist, and arm in fine motor control. *Experimental neurology*, 146(1), 159-170.
- Thaut, M.H., McIntosh, K.W., McIntosh, G.C., & Hoemberg, V. (2001) Auditory rhythmicity enhances movement and speech motor control in patients with Parkinson's disease. *Functional Neurology*. 16(2), 163-172.
- Thaut, M. H., McIntosh, G. C., Rice, R. R., Miller, R. A., Rathbun, J., & Brault, J. M. (January 01, 1996). Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Movement Disorders : Official Journal of the Movement Disorder Society*, 11, 2, 193-200.
- Tjaden, K.&Wilding, G.E. (2004). Rate and loudness manipulations in dysarthria: acoustic and Perceptual findings. *Journal of Speech, Language, and Hearing Research*, 47, 766–783.
- Tjaden, K. & Wilding, G.E. (2005). Effect of rate reduction and increased loudness on acoustic measures of anticipatory coarticulation in multiple Sclerosis and Parkinson Disease. *Journal of Speech, Language, and Hearing Research*, 48, 261–277.
- Tjaden, K., & Wilding, G. (January 01, 2011). Effects of speaking task on intelligibility in Parkinson's disease. *Clinical Linguistics & Phonetics*, 25, 2, 155-168.
- Tompkins, C.A., Bloise, C.G.R., Timko, M.L., & Baumgaetner, A. (1994). Working memory and inference revision in brain-damaged and normally aging adults. *Journal of Speech and Hearing Research*, 37: 896-912.
- Tourville, J. A., & Guenther, F. H. (August 01, 2011). The DIVA model: A neural theory of speech acquisition and production. *Language and Cognitive Processes*, 26, 7, 952-981.
- Turner, R. S., & Desmurget, M. (January 01, 2010). Basal ganglia contributions to motor control: a vigorous tutor. *Current Opinion in Neurobiology*, 20, 6, 704-16.
- Van Donkelaar, P., & Staub, J. (2000). Eye-hand coordination to visual versus remembered targets. *Experimental Brain Research*, 133(3), 414-418.
- Van Lancker Sidtis, D., Cameron, K., & Sidtis, J. J. (2012). Dramatic effects of speech task on motor and linguistic planning in severely dysfluent parkinsonian speech. *Clinical linguistics & phonetics*, 26(8), 695-711.
- Verleden, S., Vingerhoets, G., & Santens, P. (2007). Heterogeneity of cognitive dysfunction in Parkinson's disease: A cohort study. *European Neurology*, 58, 34-40.
- Van der Merwe A. A theoretical framework for the characterization of pathological speech sensorimotor control. In McNeil M.R. (Ed) *Clinical management of sensorimotor speech disorders*. New York: Thieme Medical Publishers. 1997.
- Walker, V.G. (1988). Durational characteristics of young adults during speaking and reading tasks. *Folia Phoniatica*, 40, 15.
- Wechsler, D. (1997). Wechsler Adult Intelligence Scale III. San Antonio: The Psychological Corporation.

- Wegen, E. v., Lim, I., Goede, C. d., Nieuwboer, A., Willems, A., Jones, D., . . . Zijlmans, J. (2006). The effects of visual rhythms and optic flow on stride patterns of patients with Parkinson's disease. *Parkinsonism & related disorders*, 12(1), 21-27.
- Weismer, G. (1984). Articulatory characteristics of Parkinsonian dysarthria: Segmental and phrase-level timing, spirantization, and glottal-supraglottal coordination. *The dysarthrias: Physiology, acoustics, perception, management*, 101-130.
- Werheid, K., Koch, I., Reichert, K., & Brass, M. (2007). Impaired self-initiation task preparation during task switching in Parkinson's disease. *Neuropsychologia*, 45, 273-281.
- Wichmann, T., Bergman, H., Starr, P. A., Subramanian, T., Watts, R. L., & DeLong, M. R. (1999). Comparison of MPTP-induced changes in spontaneous neuronal discharge in the internal pallidal segment and in the substantia nigra pars reticulata in primates. *Experimental Brain Research*, 125(4), 397-409.
- Willems, A.-M., Nieuwboer, A., Chavret, F., Desloovere, K., Dom, R., Rochester, L., . . . Van Wegen, E. (2006). The use of rhythmic auditory cues to influence gait in patients with Parkinson's disease, the differential effect for freezers and non-freezers, an explorative study. *Disability & Rehabilitation*, 28(11), 721-728.
- Willems, A. M., Nieuwboer, A., Chavret, F., Desloovere, K., Dom, R., Rochester, L., . . . Jones, D. (2007). Turning in Parkinson's disease patients and controls: the effect of auditory cues. *Movement Disorders*, 22(13), 1871-1878.
- Winholtz, W., & Titze, I. (1997). Conversion of a head-mounted microphone signal into calibrated SPL units. *Journal of Voice*, 11, 4, 417-421.
- Wolfe, V.I., Cornell, R., & Fitch, J. (1995). Sentence/vowel correlation in the evaluation of dysphonia. *Journal of Voice*, 9, 297-303.
- Yorkston, K.M., & Beukelman, D.R. (1981). Assessment of intelligibility of dysarthric speech. Tigard, OR: CC Publications.
- Yorkston, K.M., Beukelman, D.R., Strand, E.A., & Bell, K.A. (1999). Management of motor speech disorders in children and adults (Second ed.). Austin: PRO-ED, Inc.
- Yorkston, K.M. & Beukelman, D.R. (1978). A comparison of techniques for measuring intelligibility of dysarthric speech. *Journal of Communication Disorders*, 11, 499-512.
- Yui, E., Worrall, L.E., Longland, J., & Mitchell, C. (2000). Analyzing vocal quality of connected speech using Kay's Computerized Speech Lab: A preliminary finding. *Clinical Linguistics and Phonetics*, 14, 295-305.
- Zraick, R.I., Marshall, W., Smith-Olinde, L., & Montague, J.C. (2004). The effect of task on determination of habitual loudness. *Journal of Voice*, 18, 176-182.
- Zraick, R.I., Skaggs, S.D., & Montague, J.C. (1999). The effect of task on determination of habitual pitch. *Journal of Voice*, 14, 484-489.

Zraick, R.I., Wendel, K., & Smith-Olinde, L. (2005). The effect of speaking task on perceptual judgement of the severity of dysphonic voice. *Journal of Voice*, 19, 574-581.