EFFECTS OF SPEAKING MODE (CLEAR, HABITUAL, SLOW SPEECH) ON VOWELS AND INTELLIGIBILITY OF INDIVIDUALS WITH PARKINSON'S DISEASE

by

REBEKAH A. BUCCHERI

A dissertation submitted to the Graduate Faculty in Speech–Language–Hearing Sciences
in partial fulfillment of the requirements for the degree of Doctor of Philosophy
The City University of New York
2013

This manuscript has been read and accepted for the Graduate Faculty in Speech–Language–Hearing Sciences in satisfaction of the Dissertation requirement for the degree of Doctor of Philosophy

Date______________________ ______________________________

Douglas Whalen, Ph.D.
Chair of Examining Committee

Date______________________ ______________________________

Klara Marton, Ph.D.
Executive Officer

Supervisory Committee:

Douglas Whalen, Ph.D.

Nancy S. McGarr, Ph.D.

Lawrence J. Raphael, Ph.D.

Winifred Strange, Ph.D.

Outside Reader:

Mira Goral, Ph.D.

The City University of New York

Abstract

EFFECTS OF SPEAKING MODE (CLEAR, HABITUAL, SLOW SPEECH) ON VOWELS AND INTELLIGIBILITY OF INDIVIDUALS WITH PARKINSON'S DISEASE

by

REBEKAH A. BUCCHERI

Advisor: Douglas Whalen, Ph.D

The present study examined the effects of speaking mode (clear, habitual, slow speech) on speech production and speech perception of individuals with and without Parkinson's disease. In the speech production task there were 21 speakers who read the Farm passage in habitual, clear and slow speech modes. Acoustic analysis involving the assessment of the first and second formant frequencies was performed using vowel space areas, vowel dispersions, /i-ɑ/ distances for both tense and lax vowels produced in each of the speaking conditions. Duration ratios of both the tense and lax vowels were also examined in each condition. Effects of the conditions on perception were investigated in two listening tasks. In the first task, 3 listeners heard a subset of speakers from the production portion. In a forced choice task the listeners then selected the vowel they preferred in a given speaking condition. In the second listening task, 10 listeners used a 7-point Likert rating scale to rate 4 sentences produced in each of the 3 conditions for the 21 speakers. Production results showed that vowel space areas were larger in the clear and slow conditions compared to habitual, with no statistically significant difference between clear and slow. Results from the first listening task showed a preference for vowels in clear speech mode, and the second showed that speakers were rated most intelligible in clear speech mode.

Acknowledgements

At the party celebrating my Bachelor's degree I announced then I wanted a PhD, because it was and still is all about the hat! Since then mom and dad and Sam & Greg you have done everything to support and encouragement me throughout this entire process. Thank You for allowing me to accomplish my dream. Greg you can no longer tease me late at night when I'm studying and say in your comical voice "back to school!" those days are now officially done. I love you all!

To my extended family and friends thank you for your love and support. I am forever grateful.

To my cousin Jennifer as we always say we are NOT quitters; we always finish what we start. Thank you for reminding me of this during trying times in this process. Thank you for your endless encouragement, love and support. Thank you for giving me the most amazing goddaughter during this time. I am finally finished and will now have more time to spend with all of you.

Judith Iannotta- A friend I met our very first semester at the GC. The bond we share can never be replaced. We laughed, we cried, we screamed and yelled, we ate, drank and drank some more. Most important of all we supported and encouraged each other throughout the entire process. We will never forget" colon jam comma" from my study! Not only did I get a Ph.D but I got an amazing friend, we are alike on some many levels its scary.

SJU Speech Girls thank you for years of encouragement and support and for being such great listeners in this study. To my colleagues (you know who you are) thanks for listening.

Dr. Nancy S. McGarr- what can I say. You have been such an integral part of my life for the past 13 years. After having my first class with you as an undergrad at SJU, I decided then I wanted to be like you: a phenomenal, warm, caring, compassionate professor. This process has been all about me getting the hat like you! You have been there with me throughout my entire education, and what an honor it is to have you on my dissertation committee! Your endless words of wisdom and encouragement have pushed me through the hard times. Not only did I learn so much from a wonderful woman, but I also have gained an extraordinary friend and colleague. I hope that I am half the professor you are and that I have made you proud!

Dr. Winifred Strange thank you for taking me on when you were no longer taking students. If you hadn't I would not be here today! Thank you for being open to new things, taking me on, someone interested in speech production and a clinical population, that was completely outside your realm but you did not shy away. I will always remember the weekly meetings, the whip, the wine and most of all how incredible a mentor can be. The knowledge you and Jim instilled in me will never be forgotten. As Jim would say onwards and upwards. I am happy to have been your last child even though I knew that someday I would be put up for adoption.

Dr. Doug Whalen thank you for adopting me when I was an orphan and had half my dissertation completed. It's not easy to pick up where someone else has left off. Thank you for taking on the challenge. I am extremely grateful.

Dr. Lawrence Raphael- thank you for willingness to be on my committee, and for your invaluable input, and laughs along the way. I am extremely grateful.

To my fiancé Jon thank you for being the loving, supporting man you are, our relationship sacrificed a lot for me to finish this degree. Thank you for your understanding and love as I accomplished my dream. We are getting married soon and our life can really begin. I can't wait to see what life has in store. Thank you for your love. I love you!

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1. Introduction

Parkinson's disease (PD) affects approximately one million people in the United States, with at least 60,000 new cases reported each year (Parkinson's Action Network, 2011). The disease affects structures in the central nervous system (CNS). Specifically, the substantia nigra a mass of cells that produces dopamine, which is a neurotransmitter that allows for fluid motor control and movement. Depletion in the production of dopamine causes involuntary movements such as those seen in various stages of PD. PD is well known to be a slowly progressing neurological disorder characterized by involuntary resting tremors, muscle rigidity and weakness, mask-like facial expression, forward flexion of the trunk, and loss of postural reflexes, and speech production disorders (Anderson, Keith, Novak, and Elliot, 2002). The latter is especially relevant to this study. Typically these neurological sequelae are treated pharmacologically. However, in instances when drug therapy is no longer alleviating these symptoms, individuals may undergo surgical intervention such as deep brain stimulation- (DBS) surgery in which a stimulator is place in the subthalamic nucleus (or other areas of the brain such as thalamus and pallidum) to reduce overwhelming gross motor symptoms. The stimulator may be placed either unilaterally or bilaterally.

As noted above, individuals with Parkinson's disease acquire a motor speech disorder known as hypokinetic dysarthria. The key speech production features of hypokinetic dysarthria as a result of PD include: reduced or monoloudness, monopitch, breathy vocal quality, perceived imprecise or rapid articulation, and decreased alternating movement rates (AMRs) (i.e., limited movement of the jaw, lips, and tongue during speech) (Duffy, 1995). These adverse or deviant speech production characteristics result in an overall reduction in speech intelligibility. The severity of the dysarthria is usually dependent on progression of the disorder. Individuals in earlier stages of the disease may show only a few of these deviant characteristics resulting in a mild reduction in intelligibility; whereas those in later stages of the disease who present with a constellation of characteristics, evidence a more severe loss of speech intelligibility. DBS has been found to adversely affect speech in some cases, even while alleviating gross motor problems (Wang, Metman, Bakay, Arzbaecher, and Bernard, 2003).

Individuals with PD have different degrees of communication difficulty and often seek speech therapy early in the course of the disease to help increase speech intelligibility. Initially, problems in voice quality become apparent (e.g., monoloudness, monopitch, breathiness). One current well known therapeutic protocol to address these problems is the Lee Silverman Voice Therapy (LSVT) developed by Ramig and colleagues. "LSVT addresses major deficits underlying voice and speech in PD, namely, impaired scaling of movement amplitude and poor perception and self-regulation of vocal output" (Sapir, Ramig & Fox, 2006, p. 563). In contrast to LSVT, traditional speech therapy may incorporate techniques to slow down the rate of speech, increase loudness, and exaggerate speech articulation. All of these techniques may be taught separately, and then, once mastered individuals may integrate them to increase their speech intelligibility. However, it can be difficult for individuals to simultaneously remember all the different traditional techniques that they must use to be more effective communicators. This may be especially important since, in later stages of the disease, individuals may experience cognitive impairments (Verbaan, Marinus, Visser, van Rooden, Stiggelbout, Middelkoop, Hilten, 2007).

A technique that may provide benefits in PD is the clear speech style of speaking, which has been extensively studied in numerous diverse populations (Uchanski, 2005). Clear speech may be an alternate/additional technique to incorporate into therapy for PD. Like LSVT, it uses a much simpler patient directive to achieve improved production. For example, the directions given in the only clear speech study on Parkinson's disease by Goberman & Elmer (2005) were to "produce items as clearly as possible, as if I am having trouble hearing you or understanding you" (p. 219). This is a much simpler direction to understand and retain than those used in other traditional therapy approaches, and therefore may be more beneficial. Smiljanic & Bradlow (2009) reported that clear speech style of speaking might incorporate some of the same speaking characteristics (e.g., decreased rate, increased loudness, and over exaggerated articulation) as those seen in traditional speech therapy. In addition to the characteristics mentioned, clear speech has also been shown to enhance both temporal and spatial acoustic features leading to increased speech intelligibility. While the LSVT protocol has been intensively studied (Fox, Morrison, Ramig, and Sapir 2002; Sapir et al., 2006; Sapir, Spielman, Ramig, Story, and Fox 2007), there is a lack of research applying the concept of clear speech production strategies to persons with PD.

Given the simplicity of clear speech instructions and the communication benefits afforded by its use, it would be beneficial to know if individuals with PD while applying clear speech instruction, can increase their overall speech intelligibility. Moreover, it would also be of interest to see if individuals with PD can sustain clear speech mode for extended periods of speech (e.g., a paragraph length). Smiljanic & Bradlow (2008b) found that normal healthy individuals could sustain clear speech over a period of time required to produce a 212-word paragraph. "The intelligibility, however varied over the paragraph, in that the second and fourth portions of the paragraph were judged more intelligible" (p. 3176). If individuals with PD can achieve the same benefits as normal individuals while speaking in clear speech mode, they could benefit in terms of increasing their speech intelligibility. Thus, clear speech may have the potential to be an additional/alternate therapy option for these individuals and is thus worthy of further investigation. Alternatively, if clear speech does not have immediate applicable benefit in the clinical setting, the information obtained in this study might still give insight on the organization of vowel production of persons with PD as they attempt to vary articulatory behaviors.

Hence, the current study investigated the benefits of clear speech mode on both speech production and speech perception of individuals with Parkinson's disease. The production portion of the study focused on vowels (both tense and lax) produced in a read paragraph, within three different speaking conditions, namely habitual, slow, and clear speech. The acoustic measures made in this study included first and second formant frequencies of vowels and vowel duration. Formant frequencies were plotted in three ways: vowel space area, vowel dispersions, and /i-ɑ/ distances. The perceptual portion of the study consisted of two parts. First, three experienced listeners selected the vowel production they preferred in a forced choice comparison task. The productions in the three different speaking conditions were paired in a randomized computer generated paradigm. The purpose of this part of the perception study was to assess how the intelligibility of vowels varied across differences in the changes in speaking conditions. Second, ten experienced listeners rated the overall sentence intelligibility of four sentences extracted from the paragraph. Each sentence was taken from four different points within the paragraph and for each of the three speaking conditions. The listeners rated the production assessing sentences using a 7-point Likert scale. There were two purposes for these ratings 1) to see if clear speech was judged to be more intelligible by experienced listeners, and 2) to ascertain if individuals could sustain clear speech for the period of time required for the reading of the paragraph (approximately 2 minutes).

Chapter 2 Review of the Literature

2.1 Speech Production Research

Currently the speech production studies of individuals with Parkinson's disease (PD) who have hypokinetic dysarthria have been primarily assessed using either kinematic or acoustic analysis measures. A few kinematic studies have examined the oral structures (Canter 1965; Weismer, Yunusova, & Westbury, 2003) of individuals with PD. Caligiuri (1987) focused only on labial movement. Several researchers (Solomon, Lorrell, Robin, Rodnitzky, & Luschei, 1995; Solomon, Robin, & Luschei, 2000) focused on tongue movement. Forrest, Weismer and Turner (1989) focused on labial and mandibular movements. Taken together, these studies confirm that individuals with PD have decreased articulator strength and range of motion across labial, lingual and mandibular structures.

In contrast, the majority of studies on PD that are acoustic in nature examine the relationship among speech production, speech perception and intelligibility. These studies examine rate (i.e., slow, habitual, fast) manipulations (Hammen and Yorkston, 1996; McRae, Tjaden, & Schoonings, 2002; Tjaden, 2000; Tjaden, Rivera, Wilding & Turner, 2005; Weismer, Laures, Jeng, Kent, & Kent, 2000; Weismer, Jeng, Laures, Kent & Kent, 2001), loudness manipulations as in LSVT (Sapir, Speilman, Ramig, Story & Fox, 2007), or rate and loudness manipulations (Kleinlow, Smith and Ramig, 2001; Tjaden and Wilding. 2004). These studies all identify speech characteristics commonly addressed in therapy for individuals with PD. (e.g, increasing loudness and/or decreasing rate). Therapy may incorporate either one or many of these factors to aid in improving the speech intelligibility of an individual. Only one study examined the role of clear speech production strategies on PD (Goberman & Elmer 2005).

Several prominent production problems are seen across these studies, namely that individuals with PD have an increased rate of speech, a decrease in loudness, a decrease in vowel space and reduced intelligibility, as well as problems with consonant articulation and pitch.

Parkinson's disease has been classically defined as a disorder characterized by muscular rigidity and stiffness (Darley, Aranson & Brown 1974). With respect to kinematic studies, given that the majority of the articulators involved in speech production are comprised of muscles, one would expect to see these attributes: rigidity, stiffness and also weakness in speech musculature. Moreover, these attributes would be directly reflected in the articulation of speech impacting intelligibility. Despite the apparent importance of these attributes, speech kinematic research in this population has been limited. Weismer, et al. (2003) examined lingual and labial kinematics and employed x-ray microbeam and simultaneous acoustic recordings to examine the production of /u/, which was extracted from sentences. The microbeam data showed that "tongue backing and lip separation have significant relations to the time of F2 min for the PD group" (p. 1256). "The F2 transition extents for the PD group were reduced compared to the control group" (p. 1253). This was attributed to the reduced articulatory gestures, and thus possibly suggested a discoordination of oral structures in articulation for individuals with PD. Caligiuri (1987) using strain-gauge examined labial muscle rigidity in PD and normal control participants. Labial movement is essential for changing vocal tract length and lip rounding especially in the production of rounded vowels such as /u/. The participants with PD had greater labial stiffness, evidenced by lower displacement amplitude and velocities that require a greater amount of force to move the lower lip, than normal controls. Thus Caligiuri argued that there was a relationship between stiffness and dysarthria severity, but not necessarily with disease severity. Yunusova, Weismer, Westbury, & Lindstrom (2008) write "A comparison of movement characteristics between articulators suggested that for both dysarthria groups, tongue marker movements tended to differ from normal than from jaw or lip marker movements, across all kinematic measures" (p.609). This is consistent with Forrest, Weismer, and Turner (1989), who found a relationship between the function of the lower lip and intelligibility. In that study, the more reduced the function of the lower lip, the more severe was the dysarthria. Interestingly, in an earlier non-instrumental study Canter (1965) suggested a relationship between neuromuscular involvement and degree of articulation disturbance. His data were not obtained using instrumental measures, but rather a more basic clinical task (the diadochokinetic rate and production of /hɑ/). He suggested that the rapid, alternating movements required for this task were reduced or impaired in individuals with PD compared to normal healthy individuals. The articulation disturbances in these tasks were hypothesized to be due to the limited ability of the PD participants to: coordinate the tongue (tip and dorsum), and lips, with rapid abduction and adduction movements of the vocal folds. These results would be currently interpreted as evidence for interarticulator timing difficulties. Consistent with Caligiuri (1987), the degree of articulation disturbance was highly correlated with intelligibility of speech. On the other hand, Yunusova et al. (2008) used x-ray microbeam data to report that tongue movements of individuals with PD were relatively similar to healthy normal individuals.

The Iowa Oral Performance Instrument (IOPI) is a device that uses bulb pressure to provide information relevant to tongue and lip strength, movement and fatigue rate (www.iopimedical.com), which are all critical issues in working with persons with PD. Solomon, Lorrell, Robin, Rodnitzky, Luschei (1995) found reduced tongue strength and oral muscle fatigue in participants with PD. However, there was no correlation reported between tongue strength and speech rate. Solomon, Robin, & Luschei, (2000), used the IOPI, to investigate tongue strength, stability and endurance in patients with PD. In contrast to their previous research, they found tongue fatigue was higher for the PD. However, no significant correlations were noted for PD between tongue function and speech characteristics (e.g., articulatory imprecision, overall speech defectiveness, and interpause speech rate). Moreover, there was no significant correlation between speech rate and tongue functions. These individuals with PD demonstrated decreased tongue strength and endurance similar to the participants reported by Solomon, et al. (1995). Thus questions remain regarding what the primary source of articulatory imprecision is, especially in vowel production.

Given that each vowel is primarily produced with a different degree of mandibular, lingual and labial movements, one might expect individuals with PD to present with difficulty accomplishing these movements compared to normal healthy individuals. In 1989 Forrest, et al. reported that individuals with PD have greatly reduced mandibular displacements compared to normal healthy individuals. They hypothesized that this reduction in displacement could be what accounts for the decrease in acoustic distinctiveness (i.e., either distortions or articulatory errors reported in the classic literature in the Parkinson's population). Flege (1988) examined the lingual movements of normal healthy individuals and reported that "variations in peak velocity may be as important as timing in determining the degree of lingual undershoot of vowels spoken at a fast rate" (p. 913). Therefore, it is predictable that individuals with PD who present with the hallmark characteristics of rapid rate of speech and also present with both lingual undershoot and limited mandibular movement are less likely to reach articulatory targets such as in production of the extreme vowels /i,ɑ/. These studies suggest a critical need for therapy targeting articulation and rate, because speakers with PD have been reported to produce more syllables per second and also to have more pauses in their speech, than normal healthy individuals (Hammen & Yorkston 1996).

Objective measures and specifically kinematic speech production studies have provided insight into the role of each articulator in the production of vowels. The tongue is the primary articulator for vowel production, which not only demands differentiated tongue placement (caused by differences in the movement, velocity, and duration of gesture) but also, movements of the mandible as well as adjustments in pharyngeal cross sectional area that are related to tongue position and shape. There are limited kinematic data on these articulators in persons with PD; therefore, additional research is warranted. Thus while, the instrumental studies do provide valuable kinematic information that may be obtained during speech production, unfortunately they do not always incorporate valuable accompanying acoustic information.

There is however evidence on the relationship between speech production and speech perception in normal adults. Hence, some possible causes of control and coordination problems in the speech of persons with PD may be inferred from the literature on typical speakers. Thus, analysis of acoustical studies and the relationship between physiology and acoustic patterns may permit better understanding of overall productions. The "extreme" oral movements required for the production of /i/ and /ɑ/ in American English may be a good indicator of how persons with PD organize the acoustic contrasts of vowels. If an individual with PD is unable to produce vowels accurately, one may infer why the error(s) are occurring based on knowledge of limited kinematic information as well as obtained acoustic information. Such information has been extensively researched in productions of normal healthy individuals, but not in persons with PD.

The majority of acoustic studies of normal and PD speakers' productions of vowels have used the vowel space area as a visual and quantitative representation of vowel distinctiveness.

Vowel space area has been correlated with intelligibility judgments of habitual speech (Bradlow, et al. 1996; Weismer, et al. 2001). The studies of vowel space focus on the effects of rate manipulations in the production of vowels by the Parkinson's population (with and without DBS) and have demonstrated that, when given explicit instructions, individuals with PD can alter their speaking rate during an experiment. These rate manipulations have been shown to have an effect on acoustic vowel distinctiveness. In general, individuals with PD have slightly faster habitual articulation rates. Therefore, they produce more syllables per second (Tjaden, 2000) and have a decreased (i.e, more centralized) vowel space area as compared to normal healthy individuals. These results were reported when persons with PD were asked to speak at their habitual rate (McRae, et al. 2002; Tjaden, Rivera, Wilding and Turner 2005; Weismer, et al. 2001). Moreover, results of these studies also demonstrate that individuals with PD can deliberately manipulate their rate to either faster or slower than their self-selected habitual rate. A faster rate of speech has been associated with a smaller and more centralized vowel space as compared to that individuals' habitual rate (McRae, et al. 2002; Tjaden, et al. 2005). In contrast, the vowels of individuals with PD at slower speaking rate have been associated with a larger, and more expanded vowel space areas, and more perceptually distinct vowels, than either habitual or fast speaking rates (McRae, et al. 2002; Tjaden, et al. 2005). Tjaden & Wilding (2004) also demonstrated that individuals with PD had reduced vowel space areas when compared to the normal healthy control group, but they did not differ across conditions. In that study, the speaking conditions were slightly different in that they were habitual, slow and loud. However, there was variation in individual data, because 9 out of 12 participants showed the largest vowel space areas in the slow condition while the remaining 3 participants showed it in the loud condition. Sapir, Spielman, Ramig, Story & Fox (2007) concluded that after LSVT, their participants demonstrated an increase only in F2 for /u/. In addition to this increase in F2 for /u/ LSVT has been shown to increase SPL (sound pressure level), the duration of sustained vowel phonation, maximum range of F0, and F0 variability during a monologue speech task and also intensity for phonation and reading (Ramig, Countryman, Thompson, & Horii 1995).

This expansion of vowel space area makes the vowels more acoustically distinct. These studies do demonstrate changes in vowel spaces as a function of rate, and great variability among speakers was shown in each study. There were speakers in each of these studies who demonstrated limited to no change from their habitual rate (McRae, et al. 2002; Tjaden, 2000; Tjaden, et al. 2005; Weismer, et al. 2000 & 2001). Similar results have been reported in studies of vowel space area and deep brain stimulation (Bjarnason 2008; Kjellson, Norrby, van Doorn. 2008). There are, however also instances in the literature where the positive correlations between increased vowel space area and intelligibility were lacking (Bjarnason 2008; Kjellson, Norrby, van Doorn. 2008; McRae, et al. 2002; Tjaden, 2000; Tjaden, et al. 2005; Weismer, et al. 2000 & 2001).

2.2 Clear Speech Production

Clear speech is a style of speaking that has been shown to increase speech intelligibility by positively impacting both temporal and spatial components of speech. The majority of the studies to date have focused on normal healthy speakers and either the acoustic aspects of their production and/or the perception of their speech production and the relation to intelligibility. The effects of clear speech on various listener groups have been studied (such as normal hearing [with and without noise], hearing impaired listeners, learning impaired listeners, the elderly and persons who acquire American English as a second language). These studies with normal healthy speakers have demonstrated that clear speech affects both temporal (i.e., increased duration of segments, decreased rate) and spatial attributes (formant frequencies values for vowels that are closer to target, have increased intensity, result in increased vowel space expansion, and have an increase in spectral energy in 1000Hz-3000Hz range). Clear speech increases the acoustic distinctiveness of vowels, especially lax vowels, increases the vocal intensity of speech production by 5-8dB, and decreases speaking rate, including frequency and duration of pauses. These changes allow for increased processing time for the listeners (Picheny, Durlach & Braida, 1986). Vowel durations have been reported to increase for clear speech for both tense and lax vowels (Ferguson & Kewley-Port 2002, 2007). Specifically, vowel space was reported to be larger in clear speech with an increase in F1 for all vowels except /ɪ/ and /ɛ/ F2 was increased for the 5 front English vowels and decreased for the back English vowels (Ferguson & Kewley-Port 2002). Krause & Braida (2009) reported an increase in intensity for 1000-3000Hz range which is beneficial for the F2 & F3 of vowels. Bradlow & Bent (2002) and Krause & Braida (2004) demonstrated that normal individuals can be taught to produce clear speech at a rate that is similar to their self-selected conversational speech. Krause and Braida (2004) also found that clear speech produced a normal speaking rate that had a pause structure similar to that of conversational speech. Smiljanic & Bradlow (2008b) have shown that normal healthy individuals can alter their articulatory patterns to sustain clear speech mode for a relatively long (i.e., 212 word) paragraph. The majority of research examining effects of clear speech has been conducted on normal healthy individuals. Since studies of clear speech on disordered populations such as Parkinson’s disease (PD) are extremely limited, the potential benefits it may provide are not fully established. Goberman & Elmer (2005) examined clear speech produced by speakers with PD and found a significant positive effect of clear speech. The PD speakers decreased their articulation rate and increased mean fundamental frequency when speaking clearly. "Overall, no statistically significant changes in vowel space areas were observed, although, 7 out of 12 participants showed a greater vowel space area in clear speech than in conversational speech. This was contributed to greater tongue excursion in clear speech" (p.227).

2.3 Measures of Vowel Space

There are a number of ways to plot the relationships of vowels in a vowel space (i.e., F1 & F2 of vowels) in order to establish a graphic representation of the acoustic distinctiveness of vowels. As in Peterson & Barney (1952), the vowel space area is determined by F1 x F2 plots (quadrilaterals/ triangles) Vowel quadrilaterals and triangles are established by calculating the average of all the temporal midpoint values for F1 & F2 for each vowel type. These averages are then plotted to form a quadrilateral. The quadrilateral is then bisected into two triangles and the area of each is calculated to establish the total vowel space area. A more recent means of plotting vowel differences consists of the computation of the overall vowel-token dispersion from a centroid (Bradlow, Torretta, & Pisoni, 1996). These dispersions were found to have a higher correlation with intelligibility, which is associated with more expanded vowel space. The dispersion is calculated by calculating the length of the line that connects the centroid to the token of the vowel. Once the length of the line for token of each vowel has been calculated; the mean of all the token lines for each vowel can be obtained. This dispersion method provides more token-specific information for each individual and for each vowel. This is important because of the intra-and inter-participant variability found in normal speakers and may be especially useful in distinguishing speech disordered populations. A third method is the measurement of /i/ - /ɑ/ range (i.e., distances), which according to Bradlow (2008, email) "is measured by using basic geometry, by calculating the length of a line for one vowel to the other vowel as in the subset of vowels /i-ɑ/". Thus F1 distance and F2 distance are investigated as separate dimensions. According to Bradlow, et al. (1996), to compute this metric, one must "measure each talker's range in F1 and F2 as the difference between the maximum and minimum values on each of these dimensions" (p. 265). F1 is related to articulatory gestures for vowels that involve pharyngeal constriction and its relation to tongue height, which may be inferred from mandible positioning (Raphael, Borden and Harris 2007). The inferred relationship between lingual and mandibular movements was also seen in Stevens, (1989). During articulation in the absence of more specific kinematic measures acoustically then, F1 might then be used to infer the extent of mandibular movements, especially for extreme vowels /i-ɑ/. This method of measuring /i/-/ɑ/ distance would thus be a good means for measuring the acoustic distinctiveness of vowels in individuals with neuromuscular disorders, especially those disorders affecting the movement of the articulators as in PD. To date, the latter measures of either dispersions or /i-ɑ/ distances have not been applied to acoustic studies of persons with Parkinson's disease.

Variability has been shown in both acoustics and intelligibility for both normal and PD (Bjarnason 2008; Bradlow & Bent, 2002 Bradlow, et al. 1996; Ferguson & Kewley-Port. 2002 & 2007; Goberman & Elmer 2005; Kjellson, et al. 2008; Krause & Braida, 2002 & 2009; McRae, et al. 2002; Peterson, & Barney, 1952; Smiljanic & Bradlow, 2008; Tjaden, 2000; Tjaden, et al. 2005; Weismer, et al. 2000 & 2001). Some possible explanations for the variability include the vowel type being measured (tense or lax) vowels. Tense vowels are inherently longer in duration, require more muscular force to produce, and are more peripheral in acoustic vowel space therefore having larger vowel space areas. Lax vowels are shorter in duration, require less muscular force to produced therefore are more centralized in vowel spaces.

Lax vowels are also reduced in function words compared to content words. Also, different ways of measuring acoustic vowel space, variations in testing instructions and testing materials (e.g., continuous speech vs. isolated vowels) or the severity of the participants' disease. The vowel space area, as measured by the area of quadrilaterals/triangles and specified by mean values for 3 or 4 vowels does not provide individual token measures. Therefore it may not provide all the relevant information about vowel distinctiveness. The majority of studies comparing normal and disordered groups report results as mean values in vowel space areas, instead of dispersions which provides individual token information that might lead to more insights. Dispersions are a good indicator of individual tokens and are perhaps a good way to analyze the data of individuals with dysarthria. In addition, the F1-F2 range measure of /i/ -/ɑ/ might be used to infer an acoustic measure of mandibular movement. To date, these measures (dispersions and /i-ɑ/ distances) have not been employed in studies of disordered populations.

2.4 Speech Perception Research and Acoustic Measures of Vowels and Intelligibility

Studies of normal healthy individuals have examined the relationship between different acoustic measurements of vowels and speech intelligibility as determined by listener ratings, judgments and transcriptions. Bradlow, et al. (1996) examined the correlation of three different acoustic measuring techniques and their relationships to vowel intelligibility. They found that a measure of vowel dispersion, and also of /i/-/ɑ/ distance were highly correlated with intelligibility. Vowel dispersion additionally provided information about "specific location of each individual vowel token" (p. 265). In contrast to other studies, Bradlow, et al. (1996) found measures of vowel space (areas of the vowel triangle or quadrilateral) did not correlate with intelligibility, and lacked the information about "each individual vowel token" (p. 265). These intelligibility results were based on and derived from transcriptions of sentence materials. While these measures for normal are interesting, variability in individual vowel tokens may be extremely important in studies of disordered speakers and would thus be obscured in certain vowel acoustic measures (i.e., vowel space).

2.5 Clear Speech Perception Research

All the characteristics of clear speech mode resulted in increased vowel distinctiveness, more frequent pauses, and releasing of final stops, all contributed to the perception of increased speech intelligibility. Picheny et al. (1986) examined the effects of clear speech mode on vowel distinctiveness in vowel space area and intelligibility with normal healthy speakers. Similarly, Ferguson, (2004) and Ferguson & Kewley-Port (2002) found vowel intelligibility was significantly higher in clear speech modes for normal hearing speakers. Krause & Braida (2004) found a 78% intelligibility increase for clear speech. They suggest it may have been due to the increase in energy within the 1000-3000Hz range. In an additional study, Krause & Braida (2009) showed increasing the intensity envelope decreased the intelligibility of clear speech but only for those speakers whose formants frequencies varied in intensity. This may be an interesting finding considering that some individuals with PD produce a degraded speech signal (e.g., the result of articulatory undershooting, decreased intensity, breathy vocal quality) that may not consistently produce intense formants. A gender effect was observed in which women were more intelligible than men in clear speech than in conversation (Fergurson, 2004; Bradlow & Bent, 2002). This finding is consistent with Bradlow, et al. (1996) who found females to be more intelligible than male in normal speech. Smiljanic & Bradlow (2008b) found an increase in speech intelligibility for clear over conversational speech for short sentences, short paragraph (i.e., 112 words) and long paragraph (i.e., 212 words). To examine maintenance of clear speech, they segmented each paragraph and evaluated intelligibility at four points within each paragraph.

Clear speech was more intelligible in two of the four points within the paragraph (second and fourth). The importance of clear speech benefits and the acoustic distinctiveness of vowels and intelligibility of individuals with PD had not been investigated. Thus, we do not know if persons with PD are able to sustain the mode of production over time.

2.6 Effects of Rate Manipulation on Intelligibility

Studies of vowels production by persons with PD and other neuromuscular disorders (e.g., ALS) have examined the effects of speaking rate manipulations on acoustic vowel distinctiveness, and perceived intelligibility. The results varied within and across studies (Tjaden & Wilding 2004; McRae, et al. 2002; Turner, et al. 1995; Weismer, et al. 2000). These studies have demonstrated that individuals with PD can manipulate their speaking rates (i.e., habitual, slow and fast) using the Magnitude production paradigm. This paradigm instructs participants to speak at their normal rate applying the number (100) to it, and then speaking half as fast (50) and twice as fast (200). However, the changes in vowel distinctiveness were not consistent among all PD participants when rate was manipulated. Overall vowel distinctiveness across three rate conditions (habitual, slow and fast) demonstrated that individuals with PD have decreased vowel space area when compared to normal healthy controls. On the whole, the changes in rate led to some inconsistent changes in speech intelligibility. Weismer, et al. (2001) showed a small vowel space area for the PD groups' habitual speech and the poorest intelligibility scores for PD compared to ALS and normal healthy controls. Slow rate increased intelligibility compared to habitual rate and fast rate decreased intelligibility compared to habitual rate. Solomon, et al. (1995) also examined perceptual judgments of articulation precision and overall speech defectiveness that were obtained from four experienced SLPs. The PD group was judged to have significantly greater articulatory imprecision. Tongue strength was correlated with articulatory precision and overall severity judgments. While these results are consistent with those of Caligiuri (1987) and Canter (1965), they are not consistent within and across all studies as great variability in results have been observed.

2.7 Summary and Statement of Purpose

In summary, studies of normal healthy participants have focused on finding a relationship between acoustic measures and perceived speech rate and speech intelligibility. To a lesser extent, some of these research methods have been applied to studies of persons with disordered speech, such as Parkinson's disease. Many factors contribute to establishing these relationships: testing stimuli: single words, sentences, paragraphs, rates of speech: slow, fast, conversational; speaking conditions: loud, clear; methods for measuring vowel distinctiveness; vowel space areas, vowel dispersions, /i-ɑ/ distances', and different methods of examining perception: transcription, direct magnitude estimation, free magnitude estimation. Considering all these variables, it is not surprising to see inconsistent results across studies. This makes it difficult to directly compare results across studies between normal participants and those with speech disorders that are very different from each other. Previous studies of normal healthy participants have shown a high correlation between, vowel dispersions and /i-ɑ/ distances' with intelligibility for a production produced at the speakers' habitual rate (Bradlow, et al. 1996). A study of normal healthy participants has shown that productions in a "clear speech" mode are generally more intelligible than conversational speech (Picheny, et al. 1986).

The great variability among studies examining the relationship between acoustic vowel measures and rate manipulations emphasizes the need for the present study to establish a relationship of rate manipulation on tense and lax vowels and the acoustic distinctiveness measured through vowel space area, dispersions, and /i/-/ɑ/ F1/F2 distances. There is only one study on lax vowels and rate manipulation in individuals with PD (Tjaden, et al. 2005). The stimulus was a paragraph, and the lax vowels of interest were mainly contained within function words. In general because vowels are reduced in function words they may not be an accurate measure of lax vowel production. No studies have examined the use of paragraph-length speech and the effects of both rate (e.g., habitual and slow) and a combination of clear speech on both tense and lax vowels and the relation to speech intelligibility judgments of individuals with dysarthria as a result of PD.

Thus the purpose of this study was to establish the relationship among acoustic-measures of both tense and lax vowels, rate (slow, habitual) and clear speech, and perceived intelligibility of speech productions of individuals with hypokinetic dysarthria. This study compared PD patients with age-matched normal controls. Previous research on normal healthy individuals by Picheny, et al. (1986), reported that clear speech is more beneficial than slow speech in increasing acoustic distinctiveness of vowels and intelligibility. This motivated the current study because previous research on individuals with PD as well as current speech therapy pedagogy each focus on slowing the speech of individuals in order to increase their speech intelligibility. Based on the finding by Picheny et al. (1986), the present study incorporated a clear speech condition and compared differences among the productions in the clear speech to productions of the individuals' habitual speech and slow speech modes. It was hypothesized that the clear speech instructions would increase the acoustic distinctiveness of vowels and moreover would be more beneficial than instructions given to speak slowly. It was further hypothesized that these acoustic expansions would increase speech intelligibility of individuals with PD particularly in clear speech mode.

A 7-point Likert rating scale (1=least intelligible, 7=most intelligible) was used to rate intelligibility. The Likert rating scale was chosen to avoid biasing of ratings that may occur when using a Direct Magnitude Estimate (DME) modulus (Weismer and Laures, 2002). The present study sought to establish a relationship between speaking condition and speech intelligibility. The hypothesis was based on research showing that clear speech increases vowel distinctiveness and intelligibility of normal healthy speakers. It was expected that verification of this hypothesis for individuals with PD, might motivate further research on applying clear speech as a future therapy technique for individuals with PD.

In many previous studies, researchers primarily reported vowel quadrilaterals/triangles. This project generated 4 acoustic measures: 1) quadrilaterals/ triangles for comparison of results with other studies, 2) overall dispersion patterns, to obtain individual vowel token differences within participants, across participants, and any trends in particular vowels, 3) the /i/- /ɑ/ distance measure since it might infer mandibular opening and has also been highly correlated with intelligibility in normal speakers, and 4) relative duration measures of tense and lax vowels, which are of interest because they are a secondary cue to vowel perception in American English, and have been shown to be twice as long in clear speech mode. This project also generated 3 perception measures: 1) preference judgments for vowels in keywords containing both tense and lax vowels, 2) overall intelligibility scores for each speaking condition, and 3) the intelligibility scores for sentences across a paragraph to see if the clear speech benefit can be sustained throughout a paragraph.

Chapter 3. Production Methods

3.1 Participants

Participants were 13 individuals, ages 55 to 80 years diagnosed by a neurologist as having mild-to-moderate Parkinson's disease (PD). The participants with PD all had hypokinetic dysarthria ranging in severity from mild to severe. The speakers did not have any speech, language, voice, vision, reading or hearing disorders prior to their diagnosis of PD. In addition, none of the PD participants had received prior speech therapy for their hypokinetic dysarthria. All PD participants had PD as their primary diagnosis with no other co-morbidities. All of the PD participants were recorded one hour after the administration of their medications to equate possible medication effects across talkers.

This study also included 8 normal healthy control (NC) individuals who were age and gender matched to PD participants. All healthy control participants had no history of any neurological disorders, cerebrovascular accidents, or traumatic brain injuries. Additionally, all control participants had no prior history of speech, language, voice, vision, reading or hearing disorders.

All participants were screened to rule out dementia through the administration of the Mini-Mental State Exam (Folstein, Folstein, and McHugh, 1975). Only participants who scored from 25 to 30 participate in this study. All participants were residents of New York City or the surrounding metropolitan tri-state area. They were recruited through local Parkinson's support groups, from the PDtrials.org website, and through word of mouth.

For purposes of this study, the overall speech severity judgments were based on the habitual speech recording. Two speech-language pathologists scaled severity, estimates of each participants' speech and categorized each PD participants speech deficits as mild, mild-moderate, moderate, or severe). In addition, primary deviant speech characteristics, (based on the Darley, Aronson, and Brown (1975) perceptual classification system), were listed for participants with dysarthria. The primary researcher of this study is a licensed and certified speech-language pathologist and served as one of the judges. The second judge was another licensed and certified speech-language pathologist, with experience dealing with individuals with dysarthria.

3.2 Materials

The stimulus for this experiment was The Farm Passage by Crystal & House (1982). This passage includes 313 monosyllabic words that contain all the sounds within the American English approximating their rate of occurrence in "natural" speech. This passage has been used in studies that examined rate manipulations and vowel space areas for both tense and lax vowels (Turner, et al. 1995; McRae, et al. 2002; Tjaden, et al. 2005). The Farm Passage was used here to compare results with those of these previous studies. The passage is included in the appendix with both long (tense) /i/, /æ /[1], / ɑ /, /u/, and short (lax) vowels / ɪ /, / ɛ /, / ʌ /, & / ʊ / underlined in content words. There are a total of 37 keywords of interest containing either tense or lax vowels of interest. In addition to the underlined passage, a list of words according to vowel and contexts is provided.

The stimulus passage was chosen based on previous research examining vowels space areas in speech of individuals with dysarthria. It contains tense and lax vowels within non-nasal context (with the exception of 3 out of 37 vowels) to eliminate the effects of nasalization on the vowel formants (Pickett, 1999). Future studies should examine the effects of nasalization.

---

[1] According to Ladefoged, (2001), and Raphael, Borden, & Harris, (2007). the /æ/ vowel is phonologically considered to be a lax vowel, because it cannot appear in stressed open syllables. All research discussed in this literature review has considered / æ/ as a tense vowel based on its long duration and extreme formant values. This study will also consider it a tense vowel for comparison purposes.

The speech recordings were made using a Shure head worn microphone (SM10A) connected directly to a Marantz, CDR420 recorder. The recordings were made either in a soundproof booth or in a quiet environment; due to the physical limitations of some PD participants who could not come to the laboratory.

3.3 Procedure

The participants were allowed to read The Farm Passage quietly until they felt comfortable enough to produce the recordings. Since this project is only concerned with speech production and not language, the researcher was not concerned with any learning effects that might occur from rereading the passage.

The participants were instructed to read the passage at different rates (habitual & slow). They were instructed on how to use the magnitude production paradigm to manipulate their rate. This paradigm works by applying a number, for instance 100, to the participants' habitual rate, and then telling the participant to speak at either at twice that rate, applying the number 200, if a fast rate is required, half the rate applying the number 50, if a slow rate is required. This magnitude production paradigm has been used in previous studies examining rate manipulation on acoustic working space (Turner, et al. 1995; Tjaden, 2002; McRae, et al. 2002; Tjaden, et al. 2005). It is believed to be successful in helping participants to better self- manipulate their rate. Here, only habitual and slow rates were used. Lastly, the participants were asked to read the passage a third time given clear speech instructions, adopted from a study by Goberman & Elmer (2005). In this study, they instructed their participants "to speak as if someone cannot hear you or as if someone does not understand you" (p.215). For this study, participants initially read at a habitual rate and then read the passage using clear speech and finally read the passage using slow speech. In piloting, the researcher initially tried to counterbalance slow and clear; however, some speakers were unable to differentiate clear speech from slow speech when they had produced slow first.

3.4 Acoustic Analysis

Speech samples were analyzed using the Praat computer program. The CoolEdit 2000 program was used on all speech files to down sample from 44.1 kHz to a rate of 22.05 kHz, with a 22-bit resolution. The samples were subsequently saved to a computer for analysis. Acoustic measures of interest include the F1 and F2 values which were extracted from the temporal midpoints for all vowels under investigation: tense /i/, / æ /, / ɑ /, /u/ and lax /ɪ/, / ɛ /, / ʌ / & /ʊ /. Vowel segment durations were measured following criteria found in the literature (Turner, et al. 1995; McRae, et al. 2002). The vowel onset was determined as the point when the energy was seen in both F1 and F2 in the vocalic segment. The vowel offset was similarly defined as the cessation of energy in F1 and F2 determined by measuring the elapsed time between initial and final glottal pulses. A Praat script was written to include: a maximum formant value of 6000Hz for women and 4000-5500Hz for men, with a maximum of 5 formants, a window length of .033 seconds, a dynamic range of 30 dB, and Pre-emphasis of 50Hz with Burg analysis (Gaussian-like analysis). The script located the midpoints of the vocalic segment with a +/-.03ms start and end point. Once the formant values were established, they were then plotted in several ways for various comparisons. Comparisons such as inter-and intra-group comparisons (as seen in Tjaden, et al. 2004 & 2005 and Turner, et al. 1995) were made. Vowel formant frequency (e.g., F1 & F2) values were plotted in a vowel space area looking in order to establish differences in vowels, in participant, and across the speaking conditions. These measures would thus establish whether a speaking rate/condition would become more acoustically distinct from the talkers' habitual speaking rate.

3.5 Speech Production Data Analysis

Several measure of speech production of persons with PD and normal controls were analyzed. Vowel space areas, vowel dispersions, /i-ɑ/ distances, and vowel duration ratios, were each analyzed using a mixed design ANOVA, with both between participant factors (Group: Normal control, PD), Gender (Male, Female) and within participant factors (Condition: Habitual, Clear, Slow), vowel (4 Tense vs. 4 Lax). An alpha level of .05 was adopted for all analyses; *p* values are reported in the results. ω^2 (omega squared) was used to calculate the strength of the effect. The omega squared approach was adopted because it is conservative and relatively unbiased. The Tukey HSD post hoc test was used to analyze pairwise comparisons. There were some borderline values (values between 2 and 3 standard deviations cutoff) and the distribution of the dependent variables was not always normal; however the pattern of results did not change when borderline values were excluded or when non-parametric statistics were used. For the vowel dispersion and duration ratio analysis the vowels were defined as follows: Lax vowels; L1=ɪ, L2=ɛ, L3=ʌ, L4=ʊ, and Tense vowels; T1= i, T2=æ, T3=ɑ, T4=u. For the duration ratios, the "c/h" clear versus habitual condition ratio was established by putting the duration of the clear vowel over the duration of the same vowel produced in the habitual condition. The same calculation was done to establish the ratio for the "s/h" the slow versus habitual condition. The duration of the slow vowel was over the duration of that same vowel in the habitual condition.

Chapter 4. Speech Production Results

4.1 Vowel Space Area Results:

Table 1 shows that, in the clear condition 12 of the 21 participants (N and PD) had the largest vowel area for tense vowels, while only 10 of the 21 had the larger vowel area in the clear condition for lax vowels. For seven participants (NF1, NF3, NM3, PDF2, PDF3, PDF7 and PDM5), both tense and lax vowels showed greater vowel space in the clear condition than in the other conditions, suggesting a consistent production strategy for these 7 speakers. For the slow condition 8 of the 21 individuals had the largest area for tense vowel and 10 of the 21 for lax vowels. For six participants (NF2, NF4, NM2 and NM5 as well as PDF4 and PDM1) both tense and lax vowels showed greater vowel space in the slow speaking condition than in the other conditions (clear or habitual). In sum, only 7 individuals (3-Normal control, 4-PD) had their largest areas in the clear condition for both tense and lax vowels, while 6 individuals (4-Normal control, and 2-PD) had both their largest areas in the slow condition for both tense and lax vowels. This pattern seemed specific to individuals and not to either PD or normal. For 4 individuals (1-Normal control, and 3-PD) the tense vowel area was largest in the clear condition while the lax vowel area was largest in the slow condition. However, two additional individuals with PD had vowel space areas opposite of this. Finally, there was one individual (PDM4) who had the largest vowel area in the habitual condition only for tense vowels and a different individual (PDM7) had the largest area in the habitual condition only for lax vowels. Thus one cannot attribute a definite production strategy in speaking mode or tense/lax vowel to either PD or normal participants.

Vowel Space Areas

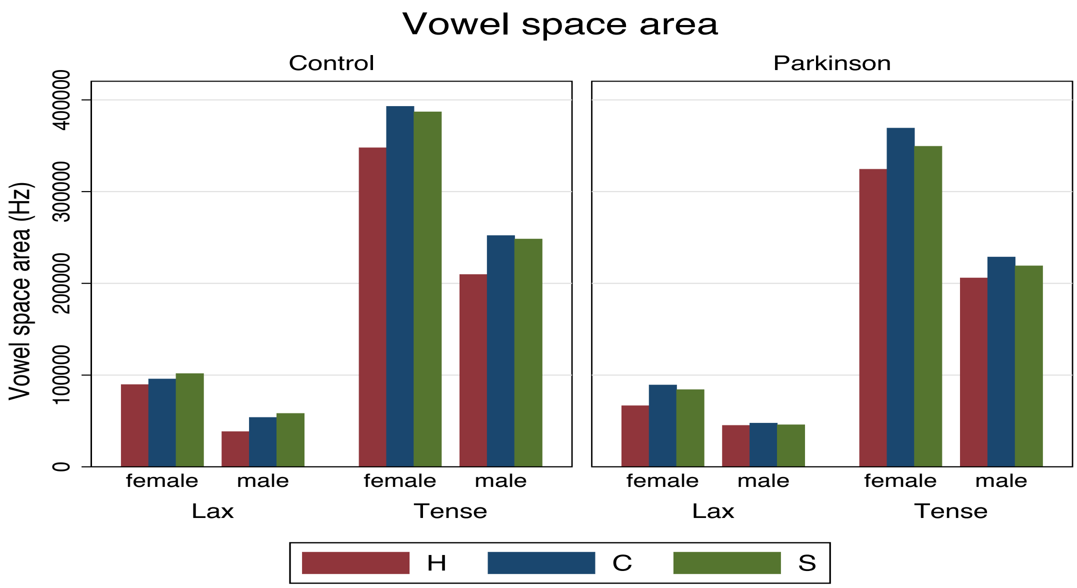
	Tense Vowel Space Areas			**Lax Vowel Space Areas**		
Speaker	**Habitual**	**Clear**	**Slow**	**Habitual**	**Clear**	**Slow**
NF1	480067.9	643940.4	488007.7	108513.8	145717.4	138297.3
NF2	325231.8	262418.2	394815.3	96895.4	80246.3	105064.8
NF3	345229.6	358273.9	348245.1	86237.3	102114.1	87641.8
NF4	240832.0	307181.0	316798.5	67049.1	55195.3	75660.8
NM2	263059.1	345120.1	364076.9	60139.5	100062.4	108928.2
NM3	200063.6	241001.2	192567.9	31533.2	38403.6	27251.7
NM4	108860.9	127147.1	125408.1	13959.4	19135.3	22887.9
NM5	266557.1	295040.9	311185.8	48229.9	57927.2	73996.5
PDF2	345331.5	509858.7	402566.3	69223.7	140169.6	102732.8
PDF3	319705.5	386982.7	360624.5	82308.5	106733.7	86167.3
PDF4	318286.5	321160.9	332769.7	70287.1	60852.9	65431.1
PDF5	463392.1	476010.7	517484.8	63978.9	101172.5	100869.0
PDF6	385698.5	360796.7	326603.9	107005.1	113791.1	120126.7
PDF7	253163.6	313488.3	304648.6	37929.2	58193.1	57174.8
PDF8	185405.2	216394.5	201500.9	35489.5	44063.7	56356.1
PDM1	234386.9	215601.7	235703.7	66103.9	47655.9	73079.6
PDM3	231130.2	268927.3	267292.6	47059.6	47655.9	47915.8
PDM4	150506.1	141774.8	146173.6	28035.4	28411.7	28232.1
PDM5	195697.3	280010.7	190324.0	43126.4	71169.7	41395.2
PDM6	238355.0	243161.5	271899.7	37927.2	54040.2	52453.9
PDM7	185696.8	222638.1	203481.3	48847.5	36811.4	32007.5

Table 1. The data in the table above shows the calculated vowel space areas expressed in Hertz for both tense and lax vowels for each speaker normal (N) and persons with PD and also for female (F) or male (M) speaker for each condition (habitual, clear and slow). The yellow highlighted cells indicate when the participants' vowel space was largest for the clear condition. The orange highlighted cells indicate when the participants' vowel space was the largest in the slow condition. Finally the two lavender cells indicated that these participants' largest spaces were in their habitual condition for either tense or lax vowels.

4.1.1 Vowel Space Area Statistical Results

The ANOVA revealed a significant main effect for Gender [$F=13.83, p=.0017, \omega^2=.0945$], Condition [$F=6.26$, $p=.0048$, $\omega^2=.0055$], and Vowel Type [$F=241.83$, $p=.0000$, $\omega^2=.6373$]. (see Figure 1). As expected, females had larger vowel spaces, as did the tense vowels. Overall, both clear and slow had larger spaces than habitual. The ANOVA also revealed two interactions:

Gender x Vowel Type [$F=10.70$, $p=.0045$, $\omega^2=.0280$] and also Condition x Vowel Type [$F=3.30$, $p=.0324$, $\omega^2=.0011$]. No significant interaction was noted for participant and any other main effect. A post hoc pairwise comparison test was conducted for the main effects of condition and also the interaction of Gender x Vowel Type, and Condition x Vowel Type using the Tukey test (see Figure 1). The comparison for condition revealed a significant difference in vowel space area between the clear and habitual conditions [$t=-5.25$, $p>.000$], and also the slow and habitual condition [$t= 4.06$, $p>.001$] with a 95% confidence interval. The vowel space area was significantly greater in the clear condition and slow condition than in the habitual condition. However, the comparison revealed no statistically significant vowel area difference between the clear and slow conditions. The post hoc analysis of vowel space area on the interaction of condition and vowel reveled a statistically significant difference between tense vowels in the habitual condition compared to the clear condition [$t=-5.61$, $p>.000$], and in the slow compared to habitual condition [$t=396$; $p>.004$]. Interestingly, there was no significant difference between the vowel space areas in the clear and slow conditions. The pairwise comparison revealed there was no significant difference between conditions for lax vowels. The post hoc analysis of vowel space area on the interaction between gender and vowel type revealed a significant difference between all comparison pairs of Gender x Vowel Type [$p>.000$] for all comparisons, with a 95% confidence interval.



(Figure. 1). Vowel Space Area in Hertz. (C= Clear speech, H=Habitual rate, S= Slow rate). Tense or lax represents tense or lax vowels. Note error bars were excluded from Figures on speech production data due to large individual speaker variability that is reflect in Formant Frequency values used to establish these figures.

4.2 /i-ɑ/ Distance Results

Table 2 shows that for 12 out of 21 individuals (5 Normal control, 7 PD) the largest /i-a/ distance was in the clear condition. Again, the clear speech condition seems to be the more enhancing speaking mode for most of the participants but not necessarily for the same participants in table 1. For only 7 participants (NF1, NF3, NM2, NM3, PDF2, PDF3, PDF7) showed a preference for clear speech strategy in these 2 measures (vowel space areas and /i- ɑ/ distance). For 6 out of 21 individuals (3 Normal control, 3 PD) the longest /i- ɑ/ distances were in the slow condition but again, not all participants were the same whose vowel areas in Table 1 showed a preference for this mode (only NF2, NM5, PDF5). Finally, for 3 out of 13 participants with Parkinson's longest /i-a/ distance was in the habitual condition. As with the vowel space results, /i- ɑ/ distance did not show a consistent pattern for all PD or all normal participants.

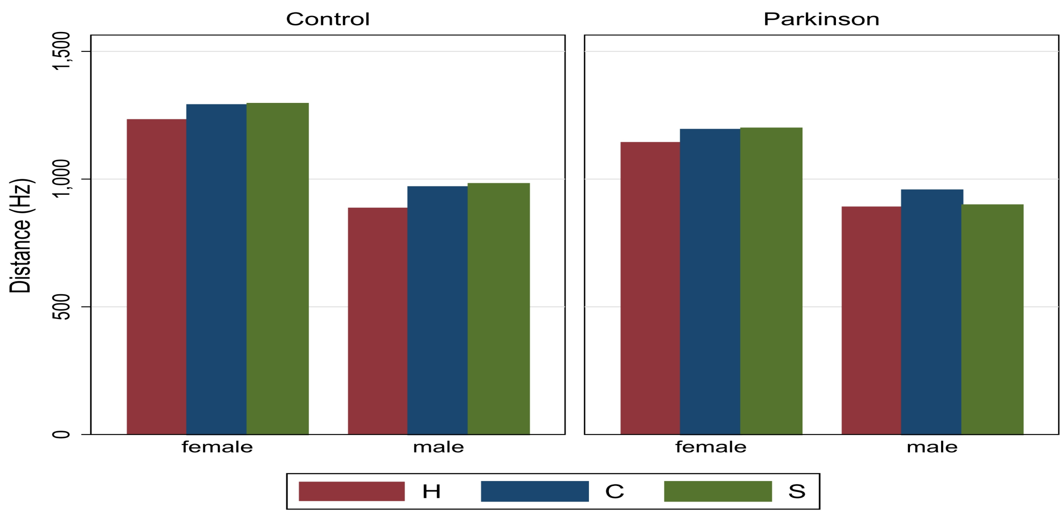
/i-ɑ/ Distances

Speaker	Habitual	Clear	Slow
NF1	1349.2	1540.9	1433.7
NF2	1290.4	1198.8	1337.0
NF3	1125.2	1165.9	1161.6
NF4	1171.9	1256.7	1250.0
NM2	1143.9	1317.1	1279.8
NM3	783.2	882.3	871.2
NM4	657.7	707.7	709.7
NM5	965.4	970.5	1066.5
PDF2	1168.8	1322.9	1319.7
PDF3	1208.9	1249.2	1232.0
PDF4	1205.7	1261.3	1251.2
PDF5	1223.3	1218.3	1282.4
PDF6	1180.5	1157.8	1110.6
PDF7	1128.3	1208.9	1200.9
PDF8	896.7	939.2	996.0
PDM1	951.0	975.6	961.8
PDM3	860.2	1158.6	984.6
PDM4	729.2	694.9	698.5
PDM5	906.8	967.5	868.4
PDM6	1041.6	1084.1	1089.6
PDM7	864.0	859.6	787.0

Table 2. The table indicates that /i- ɑ/ distance line length for each speaker in each condition (habitual, clear, slow). As in table 1 above the yellow represents all speakers who had the longest /i- ɑ/distance in the clear condition, orange indicates the longest distance in the slow condition and lavender the habitual condition.

4.2.1 /i-ɑ/ Distance Statistical Results

The ANOVA again revealed a significant main effect for Gender [F=24.75, p=.0001; ω^2=.5416] and Condition [F=6.48,p=.0041; ω^2=.0135] (see Figure 2). The ANOVA did not reveal any interactions for group x gender x condition. A post hoc Tukey pairwise comparison of conditions revealed a significant increase in /i-ɑ/ distance between the habitual condition and clear speech [t=-3.47, p=.004] with a 95% confidence interval. No other comparisons of conditions (slow vs. clear) or (slow vs. habitual) were significantly different. (see Figure. 2 below).



(Figure 2.)- shows /i-ɑ/ Distances for group (Control & PD), Gender, and condition (C= Clear speech, H=Habitual rate, S= Slow rate). Note error bars were excluded from Figures on speech production data due to large individual speaker variability that is reflect in Formant Frequency values used to establish these figures.

4.3 Vowel Dispersion Results

Comparisons of vowel dispersion across conditions (table 3a-habitual, 3b-clear, 3c-slow) clearly reveals that there were 11 speakers out of 21 who had the largest vowel dispersions for lax vowel /ʌ/ in the slow condition. The two lax vowels /ʊ/ and /ɪ/ each had 9 speakers in the slow and 9 speakers in the clear condition, whereas, there were 8 speakers who had the largest dispersion for /ɛ/ in the clear condition followed by the habitual condition with 7 speakers. Most speakers had their largest dispersion for each tense vowel in the clear condition: /ɑ/- 10-speakers, /ae/- 8-speakers, /u/- 12-speakers and /i/- 11-speakers, followed by the slow condition. Interestingly, speaker PDM7, who was the most unintelligible in the experiments reported below, did not have any vowels with greater dispersions in the slow condition.

Vowel Dispersions- Habitual Condition								
	Tense				Lax			
Speaker	/ɑ/	/ae/	/u/	/i/	/ɪ/	/ʊ/	/ɛ/	/ʌ/
NF1	444.4	298.5	691.2	940.6	143.7	292.8	389.0	360.1
NF2	462.2	403.3	605.2	855.6	199.0	361.1	239.0	398.3
NF3	395.5	334.9	736.5	747.5	170.0	336.8	235.0	357.6
NF4	456.8	279.8	331.0	736.7	125.8	386.1	168.1	305.9
NM2	403.7	213.4	528.5	758.9	128.4	311.4	269.4	287.6
NM3	258.5	302.6	470.4	573.2	94.5	169.7	223.1	308.2
NM4	202.7	155.3	261.0	487.0	112.5	129.3	143.2	223.3
NM5	358.8	246.2	477.2	705.3	107.3	307.4	213.1	342.7
PDF2	441.7	264.7	511.0	757.0	124.8	348.4	307.1	301.1
PDF3	376.3	232.7	595.9	858.2	205.3	363.4	261.5	384.5
PDF4	467.6	202.0	487.5	754.7	152.2	208.5	292.6	299.4
PDF5	413.8	249.8	747.3	890.4	221.5	237.3	246.4	283.6
PDF6	422.1	320.3	604.8	791.7	238.6	508.4	296.0	283.0
PDF7	471.9	227.1	313.7	669.4	140.4	146.3	206.4	248.5
PDF8	323.7	189.0	513.1	594.6	47.5	223.9	219.3	245.5
PDM1	255.5	301.8	593.4	761.5	201.2	294.0	200.8	262.7
PDM3	323.5	252.1	235.4	556.9	120.5	256.4	438.1	240.8
PDM4	262.5	183.5	413.2	478.9	139.9	230.6	242.5	109.4
PDM5	315.2	176.1	481.1	606.4	133.4	211.3	186.6	290.2
PDM6	341.3	208.7	528.3	726.8	84.6	279.0	222.8	231.6
PDM7	267.3	252.1	495.5	655.0	158.8	358.9	171.3	236.4

Table 3a. This table indicates each speakers mean vowel dispersions for each vowel. Individual vowel dispersion measures were calculated for each token of the vowel and averaged together to establish each mean seen above. The lavender highlighted boxes indicate that for that speaker their largest vowel dispersion mean for a specific vowel was in the habitual condition.

Vowel Dispersions- Clear Speech								
	Tense				Lax			
Speaker	/ɑ/	/ae/	/u/	/i/	/ɪ/	/ʊ/	/ɛ/	/ʌ/
NF1	439.6	348.6	788.8	1147.9	231.4	378.5	432.7	358.9
NF2	457.6	365.9	552.0	765.4	147.9	316.7	236.9	353.8
NF3	363.4	286.8	744.1	824.0	260.1	289.3	261.0	399.7
NF4	518.4	321.9	364.2	768.8	148.4	298.2	142.4	318.3
NM2	416.5	300.7	542.6	922.4	226.2	396.9	266.2	317.7
NM3	296.1	315.2	526.1	652.1	95.3	203.1	232.3	294.0
NM4	235.6	146.9	300.3	502.1	105.1	143.1	150.6	201.0
NM5	360.1	257.9	590.2	684.1	134.6	313.8	242.5	356.7
PDF2	441.0	353.7	599.0	935.6	293.7	455.4	287.6	250.2
PDF3	375.0	274.9	619.6	913.6	239.3	495.8	290.8	396.7
PDF4	479.4	215.3	451.1	797.8	150.2	281.9	221.9	211.4
PDF5	389.6	280.0	817.3	934.2	327.2	451.1	290.6	296.3
PDF6	405.7	355.7	547.1	775.1	320.6	357.7	264.4	266.0
PDF7	487.6	235.5	363.9	736.2	170.7	211.6	216.6	274.8
PDF8	314.5	216.2	544.6	656.7	131.1	216.5	203.0	231.9
PDM1	242.6	279.9	586.9	787.1	121.1	242.0	194.1	245.4
PDM3	372.2	246.8	495.0	815.0	183.4	385.3	274.2	284.5
PDM4	248.9	189.0	357.2	466.9	156.2	234.3	135.8	196.8
PDM5	343.1	191.4	607.4	663.1	146.2	240.6	200.0	306.5
PDM6	341.3	181.5	524.5	764.6	150.5	291.8	208.2	252.3
PDM7	330.8	241.0	593.7	630.5	127.2	290.9	166.2	237.4

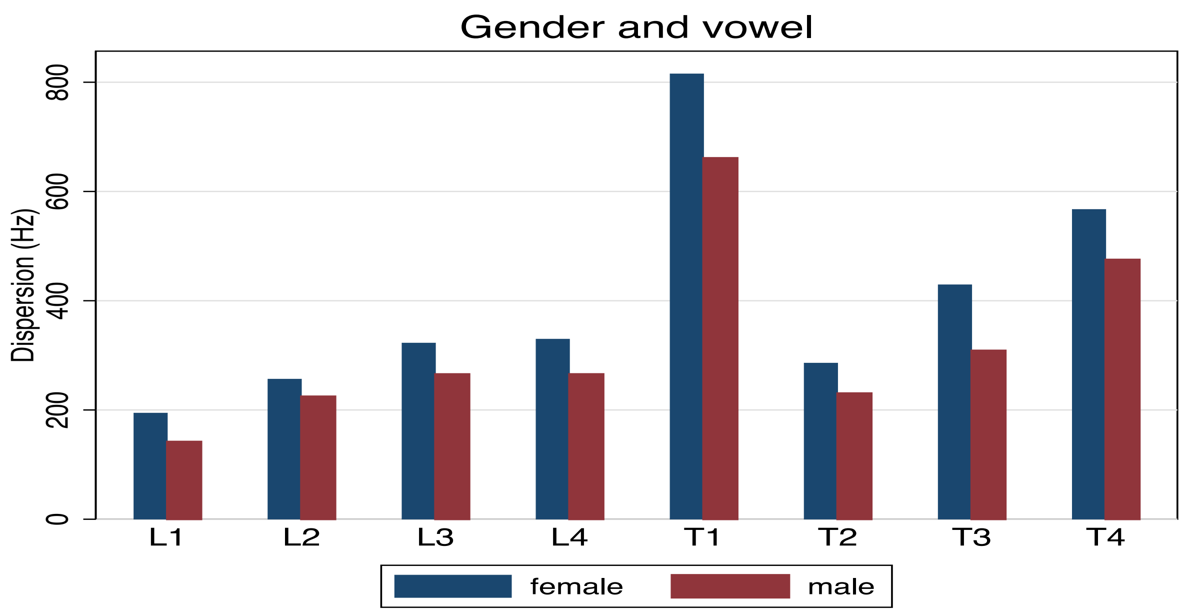
Table 3b. This table indicates each speakers mean vowel dispersions for each vowel. Individual vowel dispersion measures were calculated for each token of the vowel and averaged together to establish each mean seen above. The yellow highlighted boxes indicate that for that speaker their largest vowel dispersion mean for a specific vowel was in the clear condition.

Vowel Dispersions-Slow Condition								
	Tense				Lax			
Speaker	/ɑ/	/ae/	/u/	/i/	/ɪ/	/ʊ/	/ɛ/	/ʌ/
NF1	411.8	277.7	705.1	1054.0	243.2	408.7	383.4	421.4
NF2	491.7	409.8	637.7	874.0	243.6	334.4	228.1	429.5
NF3	385.0	285.4	653.2	791.4	201.4	303.5	223.2	360.1
NF4	487.7	334.8	307.2	775.8	132.5	259.8	184.5	438.9
NM2	396.9	250.5	600.8	902.8	217.2	445.8	312.7	366.9
NM3	268.7	271.4	449.6	642.0	84.1	135.7	211.9	265.7
NM4	214.8	140.4	317.1	535.1	91.4	185.1	161.3	209.5
NM5	356.9	294.1	574.8	803.7	176.6	346.4	226.2	400.3
PDF2	458.9	307.9	538.0	880.8	206.3	357.4	290.2	278.3
PDF3	420.5	270.1	619.8	821.1	310.5	399.1	211.9	368.4
PDF4	458.6	237.3	496.6	802.2	111.9	275.4	272.5	279.1
PDF5	458.1	288.6	808.4	924.3	339.5	368.3	267.9	375.8
PDF6	465.9	340.3	587.6	672.2	128.8	525.1	291.8	271.2
PDF7	466.0	251.2	324.9	744.7	188.1	174.5	204.9	335.1
PDF8	314.8	174.4	513.9	714.2	122.1	308.5	197.7	265.1
PDM1	271.7	292.5	636.3	735.5	217.8	309.6	239.4	298.6
PDM3	314.2	235.6	199.4	704.9	147.6	321.8	476.6	209.8
PDM4	259.4	196.2	396.2	464.4	161.1	159.9	156.1	208.2
PDM5	321.0	156.0	446.8	564.1	118.4	186.1	201.0	280.1
PDM6	364.4	206.7	527.8	743.8	186.2	305.0	210.7	274.2
PDM7	317.8	229.8	500.4	542.9	131.0	283.1	165.3	229.3

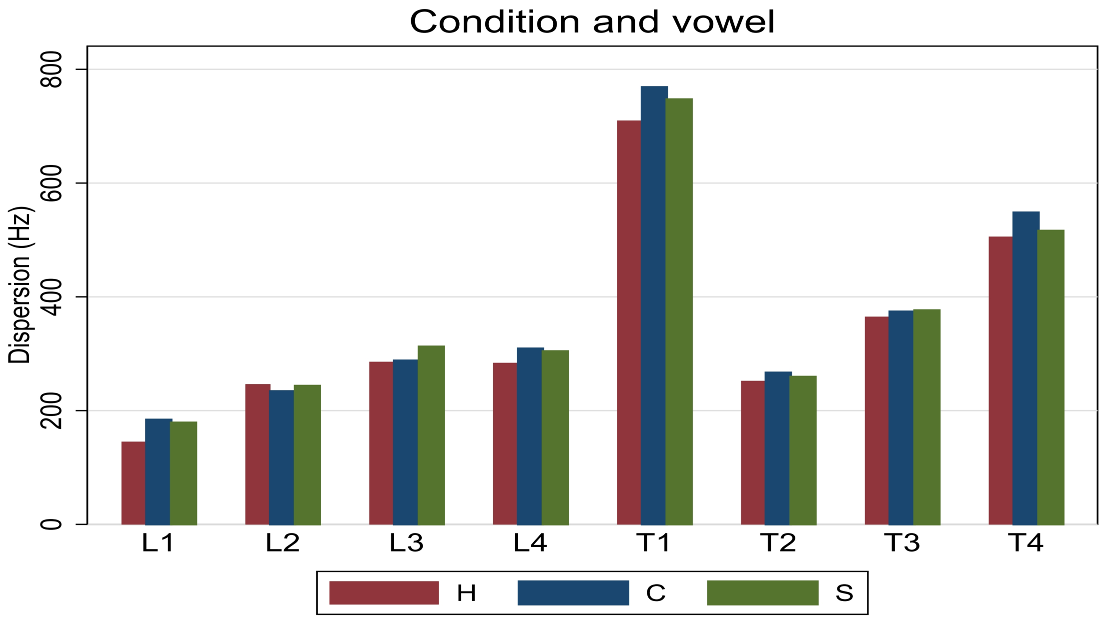
Table 3c. This table indicates each speakers mean vowel dispersions for each vowel. Individual vowel dispersion measures were calculated for each token of the vowel and averaged together to establish each mean seen above. The orange highlighted boxes indicate that for that speaker their largest vowel dispersion mean for a specific vowel was in the slow condition.

4.3.1 Vowel Dispersion Statistical Results

The ANOVA revealed significant main effects of Gender [$F=10.81$, $p>.0043$; $\omega^2=.0409$], Condition [$F=5.81$, $p=.0068$; $\omega^2=.0021$], and Vowel [$F=165.64$, $p>.0000$; $\omega^2=.7342$]. As could be expected, the females had larger dispersions than males, to match their vowel spaces, with similar considerations for the tense vs. lax vowels. Clear and slow had larger dispersions. The ANOVA also revealed significant interactions of Gender x Vowel [$F=2.09$, $p>.0495$; $\omega^2=.0088$] (see Figure 3), and Condition x Vowel [$F=2.55$, $p>.0020$; $\omega^2=.0014$] (see Figure 4). A post hoc pairwise comparison Tukey test was conducted for condition, vowel, and interactions of gender x vowel, and condition x vowel and the results are as follow. There was a significant difference in vowel dispersions as a function of condition. There was a significant difference between the habitual condition and clear speech [t= -5.73; p>.000] and the slow and habitual conditions [t=4.63, p>.000] with 95% confidence intervals. There was no significant difference between the clear and slow conditions. A pairwise comparison of vowel dispersions revealed a significant difference between all tense vowel comparison pairs (e.g. i vs. ɑ, u vs. ɑ, etc.) within each condition [p>.000] with 95% confidence intervals. The results for lax vowels were slightly different. The only pair of lax vowels found not to be significantly different from each other regardless of condition was /ʊ vs. ʌ/. The only two pairs found not to be significantly different were /æ vs. ɛ/, which are neighboring vowels, and /ʊ vs. ʌ/. A post hoc comparison of the interaction of gender x vowel was also conducted on 120 comparisons of which 107 comparisons were found to be significantly different p values ranged from [p>.000 to p>.009] with the majority being [p>.000] with a 95% confidence interval. The 13 comparisons that were not significant were those that included the comparison of paired vowels above that were found to be not significant within each gender. A comparison of conditions (habitual, clear and slow) and vowels (Lax vowels; L1=ɪ, L2=ɛ, L3=ʌ, L4=ʊ) and (Tense vowels; T1= i, T2=æ, T3=ɑ, T4=u) was also conducted. Of the total of 275 comparisons of condition x vowel, 225 were found to be significantly different, with p values ranging from [p>.000 to p>.001] with a 95 % confidence interval. When the same vowel was compared to themselves but across conditions (e.g., habitual /i/ compared to clear /i/ and habitual /u/ compared to clear /u/); the only two vowels that were both found to be significantly different from their habitual production compared to their clear speech production were /i/ and /u/. All other vowels compared to themselves across conditions were found to be not significant. These two vowels showed a significant increase in mean vowel dispersions from habitual speech to clear speech. The majority of non-significant comparisons regardless of condition and regardless of vowel order were vowel pairs /æ/ vs. /ɛ/ and /ʊ/ vs. /ʌ/. The combinations of vowels /æ/ vs. /ʌ/ in that order but regardless of condition, were also found to be not significant.



(Figure 3.) This figure shows vowel dispersions for both lax vowels (L1=ɪ, L2=ɛ, L3=ʌ, L4=ʊ) and tense vowels (T1= i, T2=æ, T3=ɑ, T4=u), across gender (female, male). Note error bars were excluded from Figures on speech production data due to large individual speaker variability that is reflect in Formant Frequency values used to establish these figures.



(Figure 4.) This figure shows vowel dispersions for both lax vowels (L1=ɪ, L2=ɛ, L3=ʌ, L4=ʊ) and tense vowels (T1= i, T2=æ, T3=ɑ, T4=u), across conditions (C= Clear speech, H=Habitual rate, S= Slow rate).

4.4 Vowel Duration Ratios Statistical Results

The duration ratios ANOVA revealed a significant main effect of Vowel [F= 6.90, p>.0000; ω^2=.1168] and an interaction of Condition x Vowel [F=2.38, p>.0260; ω^2=.0088], see Figure 5 (below). A post hoc pairwise comparison Tukey test was conducted for vowel and the interaction of condition x vowel. The vowel pair /i /vs. /ɪ/ was found to be significantly different [t=6.93; p>.000] with a 95% confidence interval. This pair /i /vs. /ɪ/ was found to be significantly different when compared within the clear condition [t=4.85, p>.000] and within the slow condition [t=4.97, p>.000] and across the comparison of slow to clear [t=2.12, p>.000]. The /u/ in the s/h comparison was found to be significantly greater than the /u/ in the c/h condition [t=4.08, p>.008] with a 95% confidence interval.

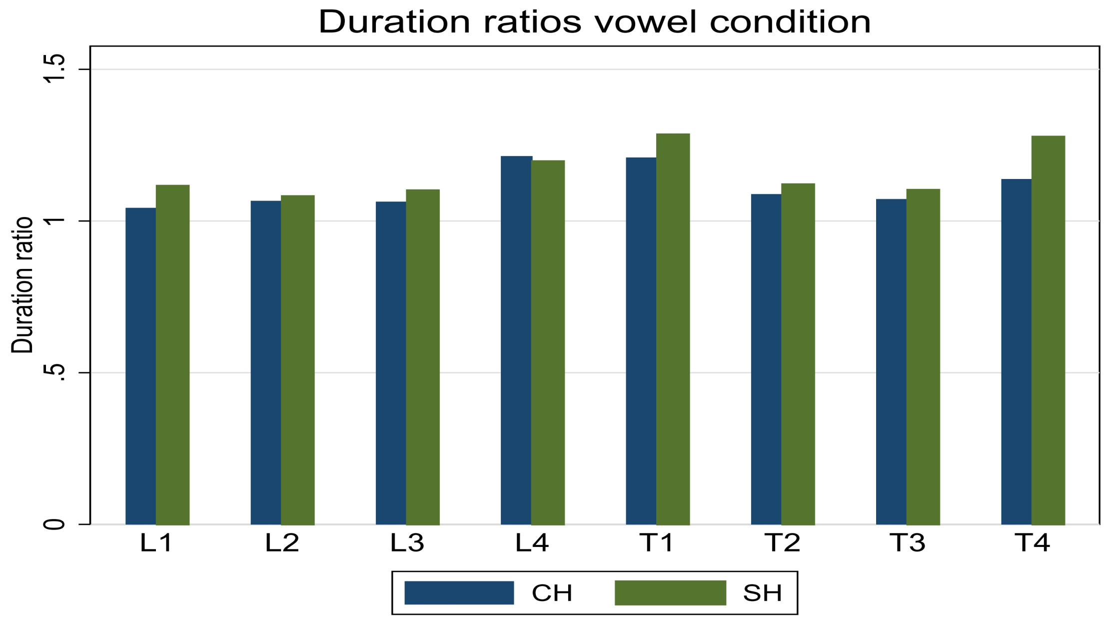
4.4.1 Vowel Duration Ratios Data

Table 4a. The table below contains duration ratios for condition (clear/habitual) for each speaker and for each vowel Lax vowels (L1=ɪ, L2=ɛ, L3=ʌ, L4=ʊ) and Tense vowels (T1= i, T2=æ, T3=ɑ, T4=u). Lavender shaded boxes are those that whose ratio did not reach a ratio of 1.

Duration Ratio- Clear/Habitual								
	/i/ T1	/ɪ/ V1	/ æ/ T2	/ ɛ/ L2	/ ɑ/ T3	/ʌ/ L3	/ u / T4	/ ʊ/ L4
NF1	2.06	1.04	1.44	1.17	1.04	1.20	1.44	1.79
NF2	0.76	1.08	0.78	0.84	1.00	0.83	0.97	0.96
NF3	1.29	1.02	1.04	1.09	1.02	1.13	1.30	1.11
NF4	1.14	1.11	1.14	1.08	1.04	1.18	1.08	1.27
NM2	1.50	1.06	1.14	1.10	1.27	1.22	1.18	1.64
NM3	1.23	1.13	1.06	1.12	1.37	0.99	1.44	1.10
NM4	0.85	0.90	0.96	1.08	1.05	1.00	0.96	1.06
NM5	0.98	0.95	1.03	1.02	0.93	1.03	1.13	1.16
PDF2	1.39	1.20	1.19	1.11	1.16	1.26	1.59	1.35
PDF3	1.11	1.02	1.02	1.13	1.02	1.01	0.94	1.19
PDF4	1.20	1.39	1.03	1.19	1.03	1.20	0.98	1.13
PDF5	1.14	1.08	1.14	1.01	1.06	1.14	1.15	1.09
PDF6	1.17	0.86	1.01	0.98	1.04	0.99	1.12	1.34
PDF7	1.06	1.23	1.30	1.16	1.15	1.26	0.98	1.37
PDF8	1.12	0.69	1.22	0.90	1.12	0.99	0.94	0.90
PDM1	1.19	0.75	0.96	1.14	0.89	0.80	1.02	1.12
PDM3	1.77	1.15	1.15	1.13	1.11	0.92	1.19	1.08
PDM4	1.06	1.05	1.05	1.10	1.09	1.01	0.86	1.40
PDM5	1.07	1.06	1.13	1.02	1.06	0.88	1.22	0.88
PDM6	1.27	1.17	1.17	1.00	1.15	1.14	1.34	1.64
PDM7	1.03	0.99	0.90	1.04	0.94	1.15	1.06	0.89

	Duration Ratio- Slow/Habitual							
	/i/ T1	/ɪ/ V1	/ æ/ T2	/ ɛ/ L2	/ ɑ/ T3	/ʌ/ L3	/ u / T4	/ ʊ/ L4
NF1	1.28	0.81	1.23	1.04	0.92	1.15	1.33	1.22
NF2	1.12	1.05	0.99	0.94	1.17	0.96	1.20	1.00
NF3	1.20	0.97	1.06	1.19	0.98	1.30	1.28	1.15
NF4	1.76	1.71	1.58	1.30	1.26	1.33	1.45	1.66
NM2	1.80	1.16	1.23	1.06	1.16	1.21	1.53	1.45
NM3	1.18	1.06	0.98	1.02	1.09	0.99	1.17	1.08
NM4	1.37	1.07	1.15	1.36	1.11	1.20	1.76	1.42
NM5	1.25	1.15	1.11	1.03	1.06	1.12	1.73	0.92
PDF2	1.47	1.04	1.03	1.20	1.13	1.08	1.08	1.01
PDF3	1.19	1.56	1.08	1.00	0.97	1.09	0.82	1.15
PDF4	1.19	1.42	1.12	1.08	1.20	1.08	1.09	1.19
PDF5	1.10	1.16	1.01	1.03	0.99	1.15	1.17	0.98
PDF6	1.14	0.85	0.95	0.95	0.96	0.96	0.97	1.22
PDF7	1.34	1.15	1.23	1.19	1.09	1.30	1.15	1.79
PDF8	1.23	0.79	1.14	0.95	1.14	1.02	1.11	0.97
PDM1	1.05	0.94	1.00	0.98	1.01	0.89	1.11	0.98
PDM3	1.60	1.27	1.20	1.13	1.21	0.92	1.79	1.12
PDM4	1.16	0.97	1.17	1.15	1.23	1.13	1.09	1.47
PDM5	0.96	1.07	0.99	1.07	1.14	0.92	1.25	1.02
PDM6	1.59	1.15	1.28	1.03	1.20	1.22	1.72	1.37
PDM7	0.99	1.07	1.01	1.03	1.15	1.09	1.04	0.97

Table 4b. This table contains the duration ratios for condition (slow/habitual) for each speaker and for each vowel Lax vowels (L1=ɪ, L2=ɛ, L3=ʌ, L4=ʊ) and Tense vowels (T1= i, T2=æ, T3=ɑ, T4=u). Lavender shaded boxes are those that whose ratio did not reach a ratio of 1.



(Figure 5.) Duration ratios and the interaction of condition and vowel. Lax vowels (L1=ɪ, L2=ɛ, L3=ʌ, L4=ʊ) and Tense vowels (T1= i, T2=æ, T3=ɑ, T4=u), CH=clear duration over habitual duration, SH= slow duration over the habitual duration to establish duration ratios of each vowel.

Chapter 5. Speech Perception Methods

Speech Perception Tasks

The perceptual portion of this study involved two separate perception tasks: 1) A two-forced choice perception task, that focused on vowel perception in target words, and 2) a Likert scale rating of sentence intelligibility. Each listening task employed a separate group of listeners.

5.1 Listeners for Task 1

The study included three experienced (those with experience with research on vowels) listeners for the perceptual task. Listeners were between ages 32-65 years. They all reported no history of speech, vision or hearing disorders. Prior to participating in this study they all dated and signed a consent form approved by the IRB of the CUNY Graduate Center.

5.1.1 Perceptual Task 1 Materials

The first listening task employed only six speakers with PD (3 males, 3 females) representing the range of dysarthria severity, and four normal healthy speakers (2 males, 2 females) who had recorded the production task. The purpose of the listening task was to determine if either speaking rate (slow) or condition (clear speech) made vowels perceptually more preferable when compared to the speakers' habitual productions. The keywords were taken from The Farm Passage and extracted from 3 word phrases, where the keyword in most instances was the middle word in the phrase (e.g., "was DEEP in", "some HASH and". The words capitalized were the keywords. The task was created in and presented via Praat software and involved comparisons of two versions of the same phrase in different conditions (i.e., habitual vs. clear speech, habitual vs. slow, clear speech vs. slow). The orders of the comparisons were also counterbalanced. For each of the speakers there were on average a total of 6 combinations of the 24 keywords x 3 speaking conditions. The task took approximately 2.5-3 hours to complete.

5.1.2 Procedures for Task 1

Listeners were seated in a quiet environment in front of a laptop with headphones and heard the stimuli at a comfortable loudness level for the listener. Praat software presented the stimuli and tracked the listeners' responses. This paired comparison task required the listeners to make a judgment about in which condition the production of the vowel in the key (underlined) word of interest sounded "better". Listeners saw and heard all the words in the phrase on top of the screen with the key word in capital letters and underlined. They heard the first token of the phrase with a one second inter-stimulus interval and then heard the second token of the phrase. At that time the listener made a decision. The next pair of stimuli was not presented until a selection had been made.

5.1.3 Listening Task 1 Analysis

It was predicted that clear speech would be preferred in all instances presented, and that slow speech would be preferred only when paired with habitual speech. Based on this prediction percentage of "correct" responses (i.e., matching predictions) were computed across each condition (habitual, clear, slow), vowel (tense and lax in American English), and individual speaker (PD and Normal).

5.2 Listeners for Task 2

The study included 10 experienced female listeners (Speech–Language Pathologists) for the perceptual task. Listeners were between the ages of 23 and 45 years. All 10 listeners were female. Male and female listeners have been shown to have similar listening results for speech stimuli even if produced by a member of the opposite sex (Whalen, Magen, Pouplier, Kang &

Iskarous. 2004). They reported no history of speech, vision or hearing disorders. They all had some experience working with individuals with dysarthria. Prior to participating, they had dated and signed a consent form approved by the IRB of the CUNY Graduate Center.

5.2.1 Perceptual Task 2 Materials

The second task used four sentences from each of the 21 (13 PD and 8 Normal) speakers recordings. Each sentence was extracted from one of 4 different locations within the paragraph (sentence 1- from the beginning of the paragraph, 2-sentences 2 and 3 from the middle, and sentence-4 from the end of the paragraph) for each of the 3 speaking conditions (habitual, clear, slow) yielding a total of 12 sentences per speaker. The total number of stimuli was 252 (21 speakers x 4 sentences x 3 conditions). Sentence at the beginning, middle or end of the read paragraph were selected to assess whether speakers were able to sustain speaking modes over the extended period of time. This is of interest because most clear speech studies do not use paragraph length material.

5.2.2 Procedures for Task 2

The listeners were seated in a quiet environment in front of a laptop with Telephonics headphones and heard the recordings at a comfortable loudness level. Praat software tracked the listeners' responses. This task required the listeners to judge how intelligible each sentence was using a 7 -point rating scale where 1-was least intelligible, and 7 was most intelligible. The task was presented through Praat software, and listener was asked to click the number on the scale that corresponded to their answer. The listeners' were allowed 1 repetition of the sentence if warranted. The test took approximately 1 hour but was self-paced and the next sentence was not presented until the listener rated the selection.

5.2.3 Listening Task 2 Analysis

Intelligibility scores were used to establish if there was a relationship between: group x condition, speaker x condition, speaker x condition x location (sentence location). Based on previous clear speech research, it was predicted that clear speech would have been rated higher in intelligibility scores over habitual and slow speech for all participants. Based on research examining rate of speech and the relation to intelligibility with PD participants (Tjaden, 2000; Tjaden, et al. 2005; Weismer, et al. 2000 & 2001), it was also predicted that slow speech would have higher scores than habitual speech only for those participants with PD. These predicted results would establish that clear speech and slow speech are preferred over habitual speaking rate in participants with PD. It was also predicted that clear speech would be preferred over both habitual and especially slow speech in normal healthy individuals. Since persons with PD have difficulty sustaining speech production over time, the intelligibility scores of sentences at the beginning, middle and end would provide evidence for this concept.

Chapter 6. Speech Perception Results-

Listening Task 1

Vowel perception data was examined using a generalized linear mixed-effects model logistic regression analysis with fixed effects for position, group, condition and vowel, and random effects including speakers and listeners. As stated before, it was predicted that when the listeners heard the pair of stimuli presented they would prefer the vowel in the pair to be in clear speech condition, when it was paired either with the habitual rate or with the slow rate of speech. In addition, it was also predicted that when the vowel in slow rate of speech was paired with only habitual speech the listener would prefer the slow vowel.

6.1.1 Listening Task 1 – Condition, Group, and Gender Results

Vowel perception data was examined using a generalized linear mixed-effects model logistic regression analysis with fixed effects for group (normal healthy control & PD), gender (of the speakers), condition (habitual, clear and slow), and their interactions. Table 5a shows the model building and comparisons for testing the effect of group, gender, and condition (and their interactions). In the table 5a, the bolded line (M5) shows the model that best fit. Table 5b. shows this final model for the comparison with standard error values.

Model	Fixed effects	Deviance	*df*	AIC[b]	LR test[a] Comparison[c]	$\chi^2(df)$	*p*
m0		-2508.4	3	5022.9			
m1	park,cond,female	-2475.9	7	4965.8	m0-m1	65.1(4)	< .001
m2	park,cond,female,park*cond	-2456.2	9	4930.4	m1-m2	39.39(2)	< .001
m3	park,cond,female,park*cond,park*female	-2449.4	10	4918.8	m2-m3	13.58(1)	< .001
m4	park,cond,female,park*cond,park*female,cond*female	-2444.3	12	4912.7	m3-m4	10.13(2)	.006
m5	**park,cond,female,park*cond,park*female,cond*female, park*cond*female**	**-2433.0**	**144893.9**		**m4-m5**	**22.74(2)**	**< .001**

Note. Speakers and Listeners included as random effects in all models. [a]Likelihood-ratio test. [b]Akaike Information Criterion. [c]Comparison between current and best model built thus far. park = Parkinson,'s group, cond = habitual speech, clear speech and slow speech, cond1 = CHHC, cond2 = CSSC, cond3 = HSSH (CHHC- clear and habitual speech compared, CSSC-clear and slow speech compared, HSSH-habitual and slow speech compared), Female-male

Table 5a. Results of generalized linear mixed-effects model comparison for probability of group, gender and condition on the listener selecting the vowel they preferred more. **Best fitting model is in bold.**

Fixed-effects	Coef.	SE	z	*p*
park	-3.145	0.359	-8.75	<.001
cond2	-1.568	0.269	-5.83	<.001
cond3	-1.294	0.275	-4.71	<.001
female	-1.518	0.384	-3.95	<.001
park*cond2	1.936	0.303	6.38	<.001
park*cond3	1.163	0.309	3.76	<.001
park*female	3.61	0.507	7.12	<.001
cond2*female	0.892	0.314	2.84	.005
cond3*female	0.49	0.318	1.54	.124
park*cond2*female	-1.733	0.422	-4.1	<.001
park*cond3*female	-1.765	0.417	-4.23	<.001
_intercept	3.033	0.322	9.43	<.001
Random-effects	Estimate[a]	SE	95% CI	
Speakers	0.276	0.078	[0.159,0.482]	
Listeners	0.172	0.082	[0.067,0.438]	

Note. [a]Standard deviation. park = Parkinson,'s group, cond = habitual speech, clear speech and slow speech, cond1 = CHHC, cond2 = CSSC, cond3 = HSSH (CHHC- clear and habitual speech compared, CSSC-clear and slow speech compared, HSSH-habitual and slow speech compared), female-male

Table 5b. Shows the effect of group, gender and condition on the listener selecting the vowel they preferred more. This is the summary of generalized linear mixed-effects final model (from M5 in table 5a) for group.

In Figure 6 (below) the effect of group, gender (of the speaker), and condition (and their interactions), were tested. The position was ignored (not tested in this analysis) and also the vowel/vowel type is ignored (not tested in this analysis). This analysis examined whether there was a difference between group, gender or condition in the listeners' ability to judge the more preferable vowel in the predicted manner.

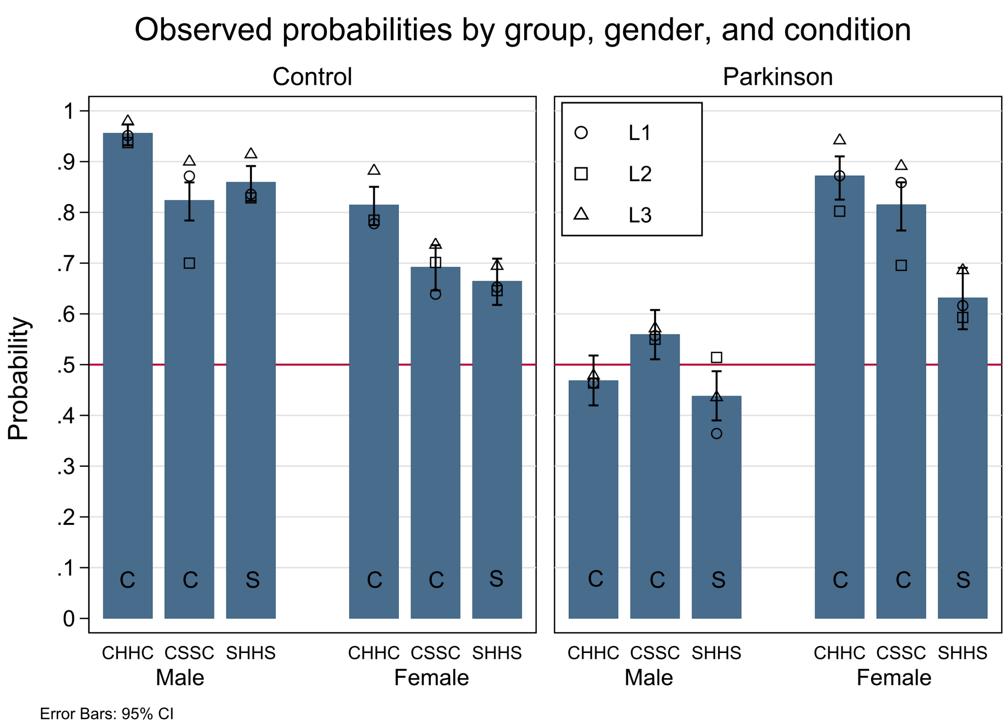


Figure 6. Shows the 3 listeners' (L1, L2, L3) ability to judge the more preferable vowel in the predicted manner. The letter C (for the clear) or S (for the slow) that is overlaid in the bars represents the predicted condition for that pair of conditions (CHHC- habitual speech and Clear speech pairs, CSSC- clear and slow speech pairs, SHHS- slow and habitual pairs).

Figure 6 shows a significant difference between group, gender and condition. Listeners preferred vowels in the predicted condition more often in the control group and PD females than PD males. In the female control group the vowels in the predicted conditions were preferred less often than by listeners than the control males [z=-3.95, p=.000]. In the PD group, there was a statistically significant difference between males and females [z=.7.12, p=.000], with a 95%

confidence interval. The PD males were also statistically significantly different from the male control group. The PD females however were indistinguishable from the control group. The figure also shows the statistically significant difference between conditions CHHC and CSSC [z=-5.83, p=.000] and CHHC and SHHS [z=-4.71, p=.000] for males in the control group. In that, listeners preferred the predicted vowels in the clear condition in the CHHC condition more often than in the CSSC condition, and also more often than the predicted slow vowels in the SHHS condition. Therefore listeners chose the vowels in the clear condition significantly more often in the CHHC condition than any other condition. For both males and females in the control group there was no significant difference between the CSSC and HSSH conditions. However, there was a statistically significant difference in the PD females between CHHC, CSSC and the HSSH conditions. There was a three way interaction for Parkinson's females between CHHC and CSSC conditions [z=-4.11; p= .000] with a 95% confidence interval; and Parkinson's females and the CHHC and SHHS conditions [z=-4.23; p =.000] with 95% confidence interval. The listeners preferred the vowel in the clear condition more often to both the habitual and slow conditions for the PD female group. The PD males were significantly different from all others participants. The listeners' preferences were slightly above and below the .05 probability level, indicating that the listeners did not often prefer the vowels of the PD males as predicted.

A post-hoc pairwise comparison revealed that although the PD males were around chance there was still a statistically significant difference between the CSSC and CHHC conditions [z=2.62; p=.009] and CSSC and SHHS conditions [z=-3.55; p=.000]. Upon further post-hoc examination it was revealed that for the control group there was significant difference between CHHC and CSSC conditions for both males [z=-5.85; p=.000] and females [z=-4.16; p=.000]. There was also a statistically significant difference between CHHC and SHHS conditions for both males [z=-4.71; p=.000] and females [z=-5.00; p=.000]. However, there was no statistically significant difference for both male and female control participants between conditions CSSC and SHHS. Post-hoc analysis of the Parkinson's female showed a statistically significant difference among all pairs of conditions, that is: conditions CHHC and CSSC [z=.193; p=.05], conditions CHHC and SHHS [z=-6.14, p=.000], and conditions CSSC and SHHS [z=-4.58; p=.000]. Since the PD females' predicted vowel preferences' were similar to the control groups, further post-hos examination were carried out revealing that the PD females, with regards to the CHHC condition, were statistically different from the control males [z=-2.57;p=.010]. They were not however, statistically different from the control females. Also, the control and PD females both had similar SHHS scores that were not statistically different. Overall this analysis shows that vowels produced in clear speech were preferred more than vowels produced in habitual or slow speech conditions, except for the of PD males in the CHHC condition.

6.1.2 Listening Task 1 – Vowel, Group and Condition Results

Vowel perception data were examined using a generalized linear mixed-effects model logistic regression analysis with fixed effects for vowel type (tense vs. lax), condition, and group (and their interactions). Table 6a shows the model building and comparisons for testing the effect of vowel type (tense vs. lax), condition, and group (and their interactions). In the table 6a, the bolded line (M7) shows the model that best fit. Table 6b. shows the final model for the results of this comparison with standard error values.

					LR test[a]		
Model	Fixed effects	Deviance	*df*	AIC[b]	Comparison[c]	$\chi^2(df)$	*p*
m0		-2508.4	3	5022.9			
m1	park,cond	-2476.1	6	4964.2	m0-m1	64.64(3)	< .001
m2	park,cond,tense	-2475.9	7	4965.9	m1-m2	.39(1)	.533
m3	park,cond,park*cond	-2456.4	8	4928.8	m1-m3	39.41(2)	< .001
m4	park,cond,tense,park*cond,tense*park	-2455.4	10	4930.9	m3-m4	1.97(2)	.373
m5	park,cond,tense,park*cond,tense*cond	-2453.0	11	4928.0	m3-m5	6.82(3)	.078
m6	park,cond,tense,park*cond,tense*cond*park	-2451.2	14	4930.5	m3-m6	10.35(6)	.111
m7	**park,cond,tense,park*cond,tense*cond3*park**	**-2452.9**	**10**	**4925.7**	**m3-m7**	**7.11(2)**	**.028**
m8	park,cond,tense,park*cond,tense*cond3	-2453.6	10	4927.1	m3-m8	5.69(2)	.058

Note. Speakers and Listeners included as random effects in all models. [a]Likelihood-ratio test. [b]Akaike Information Criterion. [c]Comparison between current and best model built thus far. park = Parkinson, cond1 = CHHC, cond2 = CSSC, cond3 = HSSH, tense= a vowel being tense, or lax.

Table 6a. Results of generalized linear mixed-effects model comparison for probability of a tense or lax vowel that was preferred more in a predicted condition for a particular group. **Best fitting model is in bold**.

Fixed-effects	Coef.	SE	z	*p*
park	-1.521	0.455	-3.34	.001
cond2	-0.947	0.136	-6.95	<.001
cond3	-0.926	0.136	-6.79	<.001
tense	0.044	0.078	0.57	.568
park*cond2	1.097	0.181	6.07	<.001
park*cond3	0.656	0.202	3.24	.001
tense*cond3*park	-0.47	0.181	-2.59	.01
_intercept	2.113	0.36	5.87	<.001
Random-effects	Estimate[a]	SE	95% CI	
Speakers	0.646	0.158	[0.4,1.042]	
Listeners	0.186	0.095	[0.068,0.504]	

Note. [a]Standard deviation. cond1 = CHHC, cond2 = CSSC, cond3 = HSSH, park = Parkinson, tense= a vowel being tense, or lax.

Table 6b. Effect of group and condition on probability of a tense or lax vowel being preferred more in a predicted condition for a particular group: Summary of generalized linear mixed-effects final model for vowel type.

Figure 7 (below) displays the results of the analysis for vowel type (tense vs. lax), condition, and group (and their interactions). Gender was not tested in this analysis.

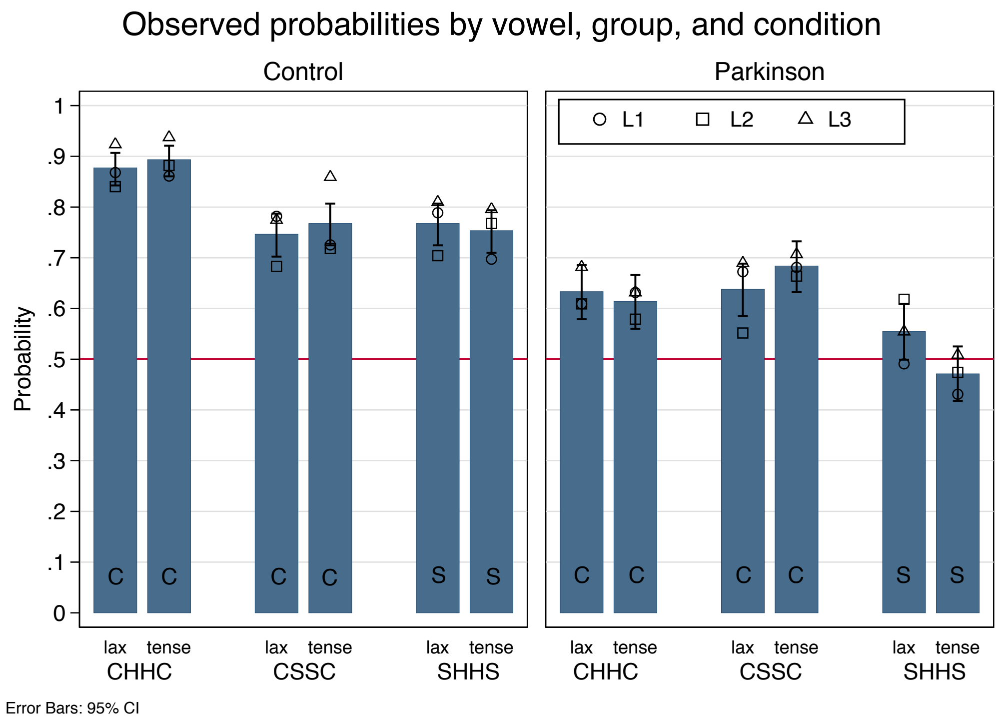


Figure 7. show data for Listeners (L1, L2, L3) for Group (Normal Control and PD), and preference for Vowel (Tense or Lax) in a Condition (Habitual, Clear, Slow). The letter C (for the clear) or S (for the slow) that is overlaid in the bars represents the predicted condition for that pair of conditions (CHHC- habitual speech and Clear speech pairs, CSSC- clear and slow speech pairs, SHHS- slow and habitual pairs).

Figure 7 shows a statistically significant difference between groups Control and PD [z=-3.34;p=.001]. Overall, listeners preferred the vowel in the predicted condition less often for the PD group compared to the control group. There was an interaction of vowel (tense), condition (SHHS) and Parkinson's group [z=-2.59;p=.010]. Although these were statistically significant differences their effects were often small. This interaction might suggest that listeners preferred hearing the habitual rate of tense vowels over the slow rate for individuals with PD.

6.1.3 Listening Task 1-Position, Condition, and Group Results

Given the results of condition seen above in section 6.1, the researcher thought it would be interesting to see if the ordering of the conditions (that is either the first of second position of the pair of stimuli) presented had an effect on listener preference. Therefore, an analysis was conducted using a generalized linear mixed-effects model logistic regression analysis with fixed effects for position (the position 1^{st} or 2^{nd} that the condition was presented in, in the pair of stimuli presented), group, and condition. Table 7a shows the model building and comparisons for examining position. This model examined the effects of position, group and condition (and their interactions). Table 7b shows the final model (M5- from table 7a) effects of position, group and condition on the probability of preferred vowel in the predicted condition.

Model	Fixed effects	Deviance	*df*	AIC[b]	LR test[a] Comparison[c]	$\chi^2(df)$	*p*
m0		-2508.4	3	5022.9			
m1	pos2,park,cond	-2470.7	7	4955.5	m0-m1	75.42(4)	< .001
m2	pos2,park,cond,female	-2470.5	8	4957.0	m1-m2	.47(1)	.494
m3	pos2,park,cond,pos2*park	-2461.3	8	4938.5	m1-m3	18.93(1)	< .001
m4	pos2,park,cond,pos2*park,pos2*cssc	-2456.9	9	4931.8	m3-m4	8.75(1)	.003
m4b	pos2,park,cond,pos2*park,pos2*cond2,pos2*cond3	-2456.3	10	4932.6	m4-m4b	1.14(1)	.285
m5	**pos2,park,cond,pos2*park,pos2*cond2,park*cond**	**-2438.3**	**11**	**4898.5**	**m4-m5**	**37.27(2)**	**< .001**
m5b	pos2,park,cond,female,pos2*park,pos2*cond2,park*cond,female*pos2		-2437.7		13	4901.5	m5-m5b
	1.03(2)	.596					
m6	pos2,park,cond,pos2*park,pos2*cond2,park*cond,pos2*park*cond		-2437.1		14	4902.2	m5-m6
	2.26(3)	.52					

Note. Speakers and Listeners included as random effects in all models. [a]Likelihood-ratio test. [b]Akaike Information Criterion. [c]Comparison between current and best model built thus far. park = Parkinson,'s group, cond = habitual speech, clear speech and slow speech, cond1 = CHHC, cond2 = CSSC, cond3 = HSSH, pos2 = vowel in the second position of the pair, female= female vs. male,

Table 7a. Results of generalized linear mixed-effects model comparison for probability of the listener selecting the preferred vowel to be in clear or slow condition**. Best fitting model in bold**.

Fixed-effects	Coef.	SE	z	*p*
pos2	0.424	0.119	3.56	<.001
park	-1.24	0.46	-2.7	.007
cond2	-1.113	0.151	-7.39	<.001
cond3	-0.933	0.137	-6.81	<.001
pos2*park	-0.599	0.142	-4.21	<.001
pos2*cond2	0.369	0.149	2.48	.013
park*cond2	1.079	0.182	5.93	<.001
park*cond3	0.422	0.18	2.34	.019
_intercept	1.942	0.362	5.37	<.001
Random-effects	Estimate[a]	SE	95% CI	
Speakers	0.646	0.158	[0.4,1.042]	
Listeners	0.187	0.095	[0.069,0.506]	

Note. [a]Standard deviation. cond1 = CHHC, cond2 = CSSC, cond3 = HSSH, park = Parkinson's group, pos2 = vowel in the second position of the pair

Table 7b. Effect of group, position, and condition on probability of the listener selecting the preferred vowel to be in the clear or slow speech condition: Summary of generalized linear mixed-effects final model for testing the effect of position, group, and condition (and their interactions).

In Figure 8 (below) the effects of position, group and condition (and their interactions) were tested. Note that the error bars in the figures are only for factors at the 95% confidence interval. In this first analysis the main effect and interactions of gender were tested and there was only an interaction for PD females; therefore, for this figure 8, further analyses collapse across gender.

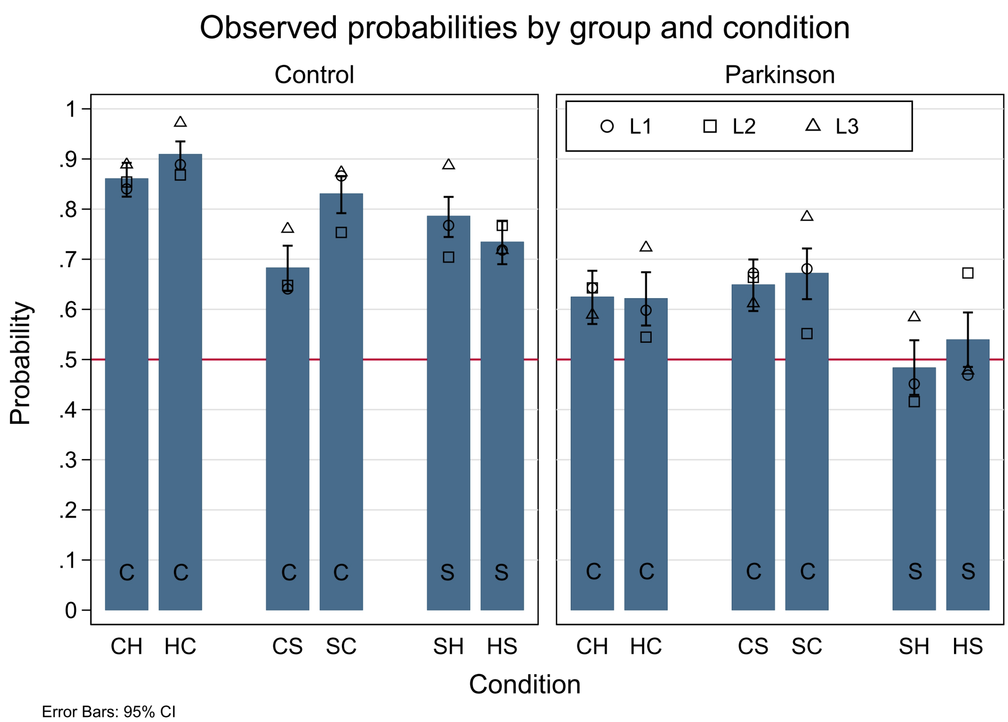


Figure 8. Contains data for Listeners 1, 2, and 3 for the control group and the PD participants. “C" is clear; "S" is slow; "H" is habitual. The data in this figure also represent paired listening conditions (e.g., CH- clear production heard first followed by the habitual, or HC- habitual production heard first followed by the clear production, etc). The predicted answer is superimposed on the data bar.

For the controls, whenever the clear condition was heard, the listeners most often preferred the vowel in clear speech over the other condition (habitual or slow). Figure 8 shows a statistically significant effect of condition (habitual, clear, and slow) for both control participants and those with Parkinson’s disease. The figure also shows that for both groups (control and PD) listeners preferred vowels within the clear condition significantly more often when paired either with the slow or habitual condition. The control group shows a statistically significant difference between the CHHC condition compared with both the CSSC condition [z=-7.39, p=.000] with 95% confidence interval, and SHHS condition; [z=-6.81, p=.000] with 95% confidence interval. The PD group also showed this difference between conditions. The CHHC was statistically different from CSSC [z=5.93,p=.000], and CHHC from SHHS of [z=2.34,p=.019] with 95% confidence intervals. However, for both groups CSSC & HSSH were not significantly different from each other. We also see that; when vowels in the habitual and slow conditions were paired, listeners chose the slow condition over the habitual conditions significantly more for the control group. This effect was not seen for the PD group: in the SHHS condition, listeners preferred either habitual or slow around chance (.5) level. This figure shows the significant difference between ordering of the conditions (CH vs. HC, CS vs. SC, and HS vs. SH) for the control group. The predicted condition (clear or slow) was judged to be more intelligible when the ordering was such that when the predicted condition was in the 2nd position, as in habitual –clear, or slow-clear, clear was chosen most often. This was only true for the SC pair and the HS pair in the PD group. This effect was statistically significant for the SC pair in the (CSSC) condition [z=2.48 p=.013], with a 95% confidence interval in the control group. The listeners preference for vowels in the predicted condition (clear and slow) for the Parkinson's group overall is lower across all conditions and shows a different pattern compared to the control group. This is not surprising considering that the PD individuals have dysarthria. One would not expect that listeners would prefer vowels in the speech of PD individual as much as normal controls even in clear and slow speech modes that are known to increase a speakers' intelligibility.

6.2 Results- Listening Task 2

6.2.1 Listening Task 2 - Intelligibility Ratings Results

Listening task 2 involved 10 listeners rating 4 sentences from the production study (sentence position 1-beginning, 2&3- middle, 4-end of the paragraph) in each of the 3 different speaking conditions (habitual speech, slow speech and clear speech) for the speakers (Normal & PD). Listeners rated the intelligibility of the speakers using a 7-point Likert rating scale where 1 was least intelligible and 7 was most intelligible. A linear mixed-effects model with cross-random effects of speakers and listeners and Multi-Level (ML) regression was used for analysis. Table 8a shows the model building and model comparison, the best-fit model is in bold (M9). Table 8b. shows the final model (M9) from table 8a. the effect of group (control & PD), gender (male, female), condition (habitual, clear, slow), position (1,2,3,4) of sentences on intelligibility ratings.

Model	Fixed effects	Deviance	*df*	AIC[b]	LR test[a] Comparison	$\chi^2(df)$	*p*
m0		-3630	4	7268			
m1	park	-3626.7	5	7263.3	m0-m1	6.63(1)	.01
m2	park,cond	-3589.1	7	7192.1	m1-m2	75.23(2)	< .001
m2b	park,cond,pos	-3562.9	10	7145.8	m2-m2b	52.28(3)	< .001
m3	park,cond,pos,female	-3562.4	11	7146.7	m2b-m3	1.11(1)	.292
m4	park,cond,female,pos,park*female	-3562.2	12	7148.4	m2b-m4	1.4(2)	.497
m5	park,cond,female,pos,cond*female	-3562.3	13	7150.6	m2b-m5	1.2(3)	.752
m6b	park,cond,female,pos,pos2*female	-3559.9	12	7143.8	m2b-m6b	12.18(4)	.016
m7	park,cond,female,pos,pos2*female,pos*cond	-3556.7	18	7149.4	m6b-m7	6.42(6)	.378
m8	park,cond,female,pos,pos2*female,pos4*park	-3552.9	13	7131.8	m6b-m8	14.04(1)	< .001
m9	**park,cond,female,pos,pos2*female,pos4*park,cond*park**	**-3549.9**	**15**	**7129.8**	**m8-m9**	**5.99(2)**	**.05**
m10	park,cond,female,pos,pos2*female,pos4*park,cond*park,park*cond*pos	-3543.4	29	7144.8	m9-m10	13.03(14)	.524
m11	park,cond,female,pos,pos2*female,pos4*park,cond*park,park*cond*female	-3547.6	20	7135.2	m9-m11	4.61(5)	.465
m12	park,cond,female,pos,pos2*female,pos4*park,cond*park,park*pos*female	-3544.3	23	7134.6	m9-m12	11.2(8)	.191
m13	park,cond,female,pos,pos2*female,pos4*park,cond*park,cond*pos*female	-3538.2	31	7138.4	m9-m13	23.41(16)	.1
m14	park,cond,female,pos,pos2*female,pos4*park,cond*park,cond*pos*female*park	-3525.2	51	7152.4	m9-m14	49.35(36)	.07

Note. Speakers and Listeners included as random effects in all models. [a]Likelihood-ratio test. [b]Akaike Information Criterion. [c]Comparison between current and best model built thus far. park = Parkinson; cond = Habitual, clear, slow condition, pos = sentence position 1,2,3,4 , female= gender female or male.

Table 8a. Results of linear mixed-effects model comparison for speech intelligibility ratings. **Best fitting model in bold.**

Fixed-effects	Coef.	SE	z	*p*
park	-1.359	0.399	-3.41	.001
cond1	-0.049	0.077	-0.64	.52
cond2	0.312	0.076	4.08	<.001
female	0.359	0.384	0.94	.35
pos2	-0.278	0.072	-3.87	<.001
pos3	-0.36	0.054	-6.61	<.001
pos4	-0.527	0.079	-6.71	<.001
pos2*female	0.202	0.089	2.27	.023
pos4*park	0.344	0.092	3.76	<.001
cond1*park	0.236	0.097	2.43	.015
cond2*park	0.144	0.097	1.48	.138
_intercept	5.356	0.448	11.95	<.001
Random-effects	Estimate[a]	SE	95% CI	
Speakers	0.872	0.137	[0.641,1.188]	
Listeners	0.803	0.182	[0.516,1.252]	
Residual	0.965	0.014	[0.939,0.992]	

Note. [a]Standard deviation. park = Parkinson, cond0 = habitual (reference level), cond1 = Slow, cond2 = Clear, pos = 1,2,3,4 refers to sentence location.

Table 8b. Effect of group, gender, position and condition on intelligibility ratings: Summary of linear mixed-effects final model for intelligibility ratings.

Results of this listening task with 10 experienced listeners show that there is a statistically significant difference in intelligibility scores between groups (control speaker & Parkinson's speakers) [z=-3.41; p=.001]. Figure 9 (below) shows the effect of condition (habitual, slow and clear) and intelligibility scores between groups (control speakers & PD speakers). For the control group there was no statistically significant difference in intelligibility scores between the slow and habitual condition [z=-0.64;p=.52]. There was, however a statistically significant difference between the clear and habitual condition [z=4.08; p<.001] with 95% confidence intervals. A post hoc pairwise comparison confirmed these results. The post hoc analysis also revealed that there was a statistically significant difference in intelligibility scores between clear speech and slow speech [z=4.72; p=.000] with 95% confidence interval.

Figure 9 also shows that there was a statistically significant difference between speaking conditions for Parkinson's individuals. That is, individuals with Parkinson's were rated more intelligible in the clear condition compared to both the slow and habitual conditions. The slow condition however, was more intelligible than the habitual condition. A post hoc pairwise comparison revealed that there was a statistically significant difference between the clear and habitual was [z=7.61; p=.000], clear and the slow [z=4.49; p=.000], and slow with habitual [z=3.12;p=.002] all with 95% confidence intervals.

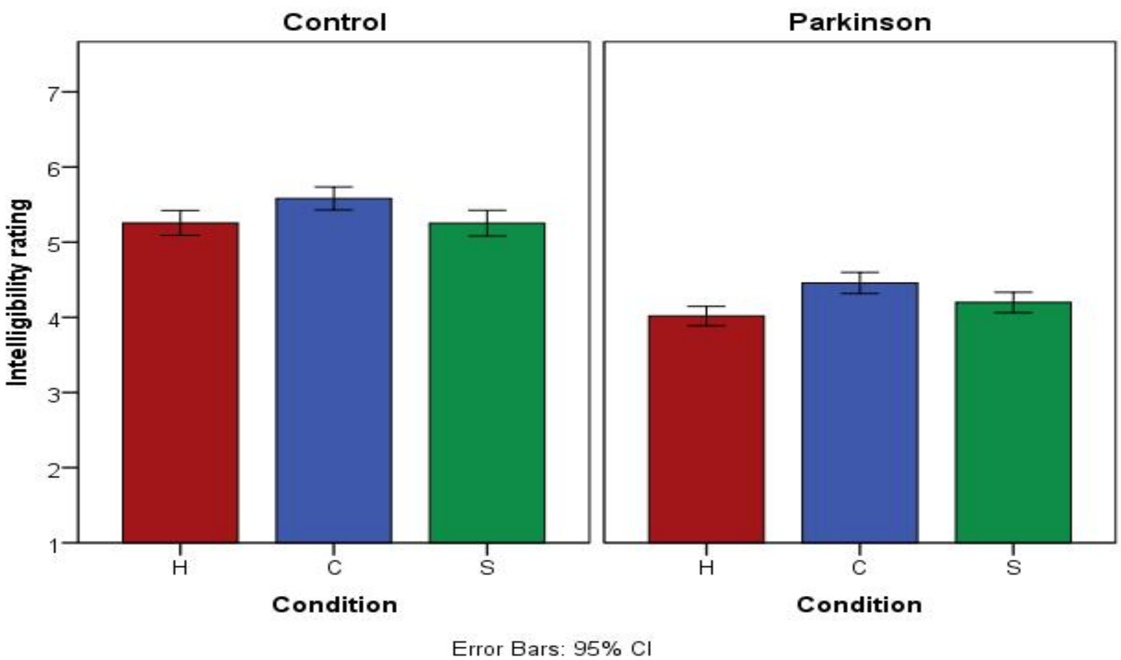


Figure 9. Shows the effect of groups (Normal Control & Parkinson's), condition (habitual, slow and clear) and Intelligibility score (1=least -7=most intelligible).

Results in Figure 10 indicate that there is a statistically significant effect of sentence position (1,2,3,4). However, there was no interaction between position and condition. Sentences 2,3, and 4 were significantly different than sentence 1 for the control group [z=-3.87;p=.000]; [z=-6.61;p=.000]; [z=-6.71; p=.000] with 95% confidence respectively. A post hoc pairwise analysis confirmed that for the control group sentences 2,3, and 4 were statistically significantly different from sentence 1 [z=-2.08;p=.038]; [z=-3.90;p=.000]; [z=-5.92;p=.000] with 95% confidence interval. The post hoc also revealed that there was a statistically significant difference between sentence 4 and 2 [z=-3.84;p=.000] and 4 and 3[z=-2.01; p=.0444] with 95% confidence interval. The post hoc analysis also revealed that sentences 2,3, and 4 were also different from sentence 1 in Parkinson's participants [z=-2.38;p=.017]; [z=-5.35;p=.000];[z=-2.70;p=.007]. The analysis also showed that there was a statistically significant difference between sentences 3 and 2 [z=-2.97;p=.003] and sentence 4 and 3 [z=2.65;p=.008]. The graph also shows a statistically significant interaction between Parkinson's participants and position 4 [z=3.76;p=.000]. The effects of position (1,2,3) are the same in the control and Parkinson's groups. That is there is a monotonic decrease in the control groups' intelligibility scores from sentence 1 through 4, but not for the PD group where, the intelligibility score increases for position 4.

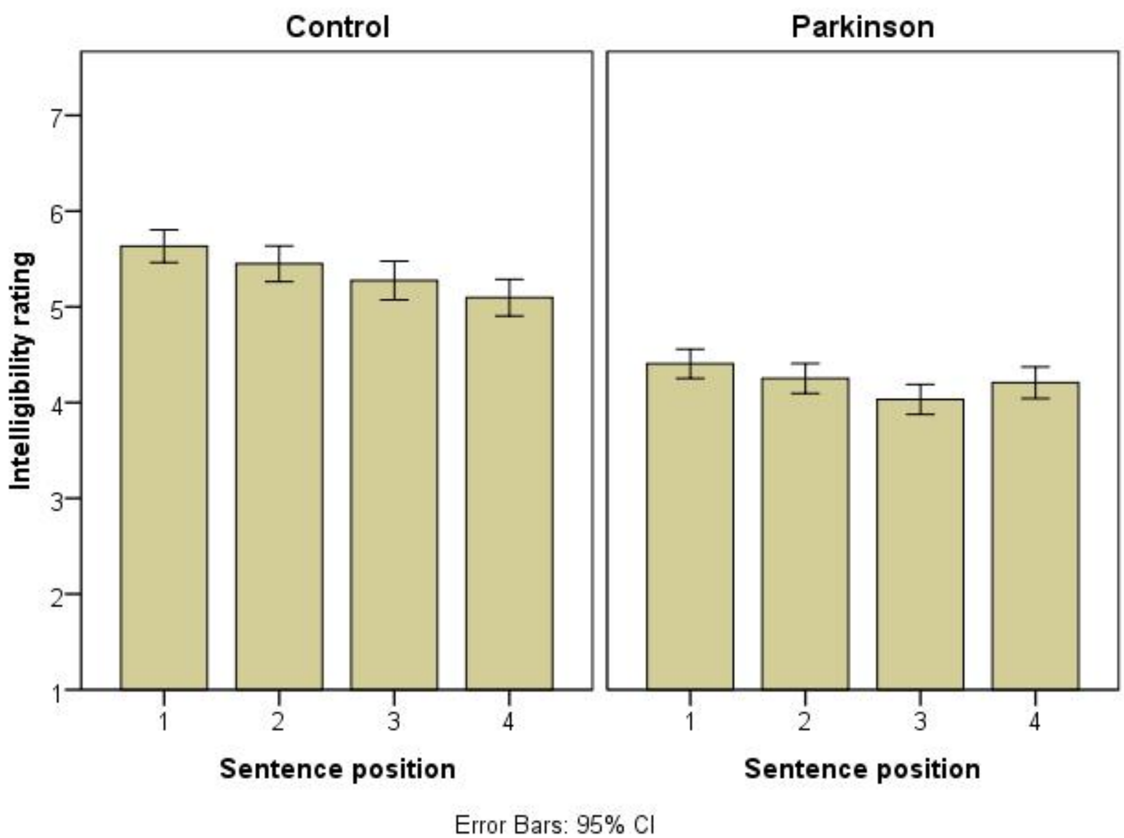


Figure 10. Shows intelligibility scores (1=least, 7=most intelligible) for the groups (Control and PD), and Sentence position (1,2,3,4).

Figure 11. shows the effects of gender on position, regardless of group (Control and PD). The results show that there was only an interaction for sentence position 2 and females [z=2.27;p=.023] with 95% confidence interval. That is females were able to maintain

intelligibility from sentence 1 to 2. The effect of sentence position 2 was different for males and females. That is position 2 is significantly different from position 1 in males, in that their intelligibility scores decrease significantly from 1 to 2.

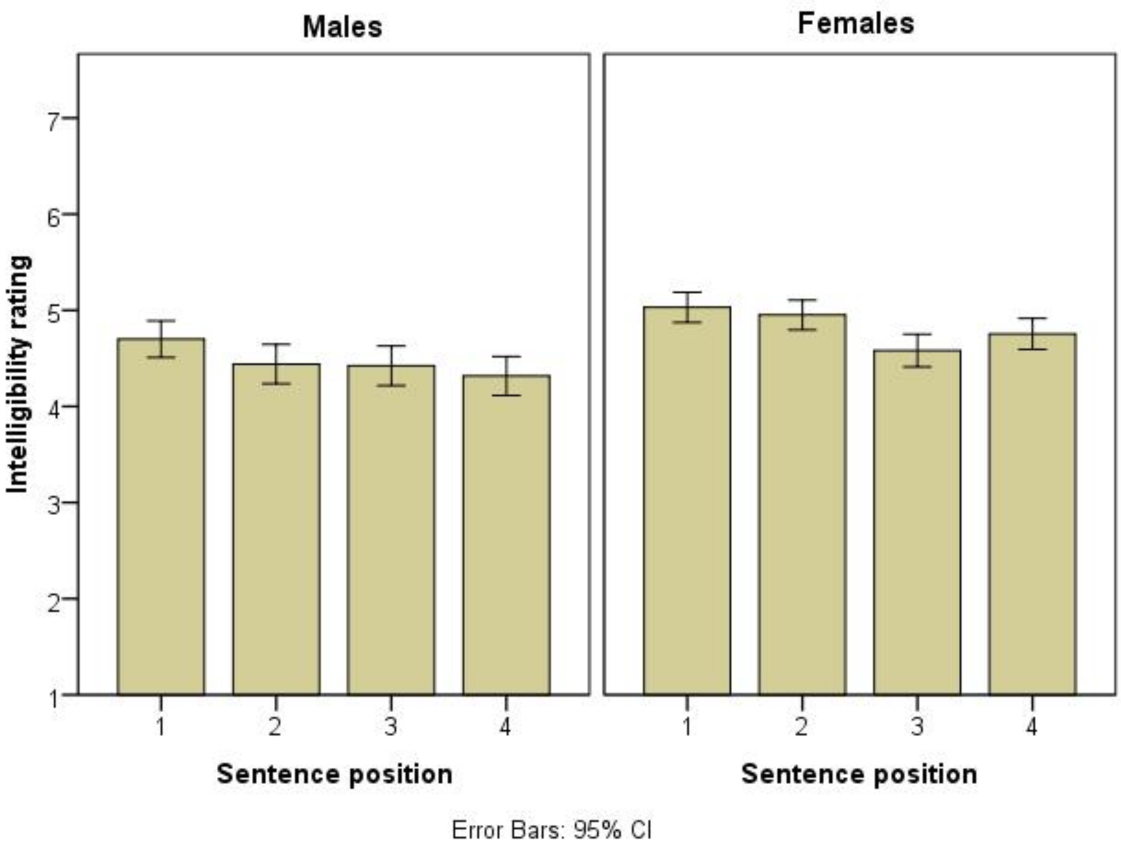


Figure 11. Examines that the effects of gender (male & female) regardless of group (Normal & PD) on position (sentence 1,2,3,4) and intelligibility scores (1=least, 7=most intelligible)

Chapter 7. Discussion and Conclusion

7.1 Speech Production Discussion

7.1.1 Vowel Space Area Discussion

The effects of speaking condition (habitual, slow and clear speech) on acoustic correlates of vowels (F1, F2 and duration) and their perceptual consequences were examined in this study. Given that results of clear speech studies with normal healthy individuals show an increase in vowel space area and the relation to intelligibility, it was hypothesized that vowel space area would increase in the clear speech from the habitual rate, and be more beneficial in increasing the acoustic distinctiveness of vowels more so then in the slow condition, and thereby increase the intelligibility of vowels produced by persons with PD. Results show that there were few statistically significant acoustic difference between the groups (control and PD). Results of this study support the hypothesis that there was a statistically significant difference between vowel space areas for clear speech compared to habitual rate of speech. Results also indicate that there was statistically significant difference between the slow rate of speech compared to the habitual rate. However, there was no significant difference between the vowel space areas in the clear speech condition compared to the slow rate of speaking. Both speaking slowly and clearly showed increased vowel space areas to varying degrees, although both control and PD speakers followed no specific pattern favoring one or the other condition. This is because the tense and lax vowels behaved differently in different speaking conditions across speakers. For example, only 7 individuals showed a consistent increase in vowel space areas for both their tense and lax vowels in the clear condition, whereas 6 other individuals showed a consistent increase in vowel space across vowel types in the slow condition. There were two PD individuals (PDM4-Tense vowels, & PDM7-Lax vowels) who showed no increase in vowel space area from habitual speech to either the clear or slow speech conditions, indicating that rate manipulation had no effect on their formant frequencies. This is consistent with previous studies on rate manipulations (slow, habitual, fast) where some participants showed little to no change in vowel spaces, although no studies examine clear speech. (McRae et al. 2002; Tjaden 2004; Tjaden et al. 2005; Weismer et al. 2000 & 2001). One possible explanation for this is the habitual rate of the speakers. If some speakers either with or without PD are habitually slower than others one might not expect to see change in their vowels space area for the slow speaking condition. The same principle could be applied for previous studies that focus on increasing the rate of speech. Due to the differences in speakers, stimuli, and speech conditions between this study and previous studies it is hard to make direct comparisons. One definitive commonality that can be found within this study and across previous studies is the variability in the speakers' tendency to increase vowel space areas for different speaking conditions, albeit there is variation in an individual speakers' strategy. The results of the vowel space area increases in this study support those of Picheny et al. (1985) and Ferguson and Kewley-Port (2002), which suggest that clear speech increases vowel space areas. In this study there was no statistically significant difference in lax vowel space, albeit some individuals did have an increase in vowel space are from habitual to clear speech. This study does not support their assertion that it does so especially for lax vowels. This study also supports previous studies that incorporate slow rate of speech as part of rate manipulation effects on vowels, which shows that only some participants increase their vowel spaces in slow speech (McRae et al. 2002; Tjaden et al. 2005). Most previous studies have examined either tense or lax vowels but not both combined.

Goberman & Elmer (2005) conducted the only known previous study examining clear speech effect on individuals with PD. While they reported no statistically significant difference between vowel space area for clear and conversational speech, 7 out of 12 of their speakers demonstrated larger vowel space areas for the clear speech. The current study, however, finds that there was a statistically significant difference in vowel space area between the speakers' habitual speech and either clear speech or slow rate of speech. In the current study 8 out of 13 individuals with PD showed larger vowel space areas in the clear condition for tense vowels; this is consistent with Goberman & Elmer (2005), and 7 out of 13 for lax vowels, 4 out of 8 control participants showed larger vowel spaces for tense vowels and 3 out of 8 for lax vowels in the clear speech condition. This finding on normal participants is consistent with previous research showing that vowel space area expands with clear speech mode (Picheny et al. 1985; Ferguson & Kewley-Port 2002; Smiljanic & Bradlow 2007). One possibility in the difference between Goberman & Elmer (2005) and this study is that Goberman & Elmer had a different task; they used vowels produced in hVd within a carrier phrase for evaluating vowels space area. Therefore, the difference can be due to coarticulation effects. The fact that some individuals with PD also increased their vowel space for clear speech suggests that some PD individuals are making articulatory adjustment similar to those of normal participant. No statistically significant difference was found between normal control and PD individuals for vowel space area. This is consistent with a previous study by Tjaden and Wilding (2004), which showed that PD participants had reduced vowel space areas that were not however, statistically significantly different from normal control participants. Speaker PDM7 was judged to have the most severe dysarthria with a rapid rate of speech. Typically therapy would focus on slowing his rate of speech. This participant's tense vowel space area, although larger for the slow speech condition, was largest in the clear speech condition, indicating that clear speech made his tense vowels more acoustically distinct than slow speech. This was not observed for this participants' lax vowel space, as his largest vowel space was in his habitual speech, indicating that neither clear nor slow speech provided any acoustic benefit to his lax vowel space. The example from this participant further supports the need for alternate or additional therapeutic approaches for individuals with PD. All other participants except for one other PD Male (PDM4) showed increases in vowel space for tense vowels as a function of condition. In addition, there was a difference between genders, which is not surprising, as we know from the classic Peterson & Barney (1952) study that women have higher formant values than men do. Neel (2008) has also shown that women have larger vowel space areas and larger mean F1 & F2 range values. Although, there was no statistically significant difference between the clear and slow speaking conditions, both provide some acoustic benefit, which may provide benefit to a person with Parkinson's disease. Further investigation is warranted on the benefits of clear vs. slow speech for individuals with PD.

7.1.2 /i-ɑ/ Distances Discussion

In regards to /i-ɑ/ distances, it was predicated that the longest distances would be seen in the clear condition. Regardless of group, the largest distances were generally seen in the clear condition (12 out of 21 individuals (5 Normal controls and 7 PD)). Eight (3 Normal controls and 5 PD) of these 12 individuals who had their largest /i-ɑ/ distances in clear speech also had their largest tense vowel space in clear speech condition. There was a total of 6 individuals (3 Normal control and 3 PD) for whom the largest /i-ɑ/ distances were seen in the slow condition. For these individuals a slow rate of speech produced the greatest /i-ɑ/ distance. Four (2 Normal controls and 2 PD) of these six individuals who had their largest /i-ɑ/ distances in slows speech also had their largest tense vowel space in slow speech condition. Given instructions to change speaking conditions 77% (10 out of 13) speakers with PD demonstrated an increased the /i-ɑ/ distances from the habitual condition. This measure, as previously discussed, might possibly imply the extent of mandible movement. If a person raises and lowers their mandible more, it will be reflected in the increased length of the line. The current study may then allow us to infer that, at least for 10 PD speakers, altering their speech from habitual may result in greater lingual and/or mandibular excursions for /i/ and /ɑ/, possibly increasing their intelligibility. Forest et al. (1989) found that mandibular movement in individuals with PD is reduced compared to normal controls. In the absence of kinematic information, this /i- ɑ/ distance, may be useful in devising therapeutic techniques to help individuals with PD to increase their vowel intelligibility, since /i-ɑ/ distance was shown by Bradlow, et al (1996) to be correlated with increased intelligibility. It may also be helpful in decreasing centralization of vowels in general. On the other hand, three individuals with PD (PDF6, PDM4 PDM7) had their greatest /i-ɑ/ distance in their habitual speech. One such participant (PDM4) not only had his greatest /i-ɑ/ distance in his habitual speech, but also his greatest tense vowel space area was also in his habitual speech condition. Participant (PDM4), shows centralization of tense vowels across the speaking condition (clear and slow) as these condition did not acoustically enhance the formant frequencies of his tense vowels as expected, measured by vowels space area or /i-ɑ/ distance.

7.1.3 Vowel Dispersion Discussion

Vowel dispersions were used to provide vowel-specific information that is not available from calculating vowel space areas alone. Here the researcher compared the mean vowel dispersions for each of the vowels across conditions. Overall, there was a statistically significant difference in vowel dispersions as a function of condition. The clear condition was significantly different from the habitual, as was the slow condition. As with the vowel space areas, there was no statistically significant difference between the clear and slow conditions. When looking at a specific vowel across the three condition, it was found that only the vowels /i/ and /u/ were statistically significantly different between clear and habitual speech. Upon inspection of the data in tables 3a, 3b, and 3c, both tense vowels /i/ and /u/ tended to have the longest lines from the centroid in clear speech, making them more dispersed from habitual speech. This finding is in some agreement with Bradlow (2002) who when measuring vowel space area of clear speech, found that vowels /i/ and /u/ were more extreme. Since both of the vowels are considered high vowels differing by tongue advancement (front and back), it may suggest that the tongue may be advancing forward more or retracting more for the production of these vowels in the clear condition. A future study is necessary to solidify this suggestion. This however, should be reflected in significant changes in F2 values for these two tense vowels. These two vowels would also be distinctly different from other vowels (especially the lax vowels), which have the shorter dispersions. There was no significant difference for these vowels between the habitual and slow condition or slow and clear conditions. For the majority of the participants, the longer dispersions were generally seen in the clear condition for tense vowels. This finding is consistent with that of Smiljanic & Bradlow (2005) who found greater vowel dispersions in clear speech compared to conversational speech for tense vowels /i/, /u/, and /ɑ/. In contrast, for nine speakers in the clear and nine in the slow conditions, the lax vowels /ɪ/ and /ʊ/ had the larger dispersions than those vowels in the habitual condition. For /ɛ/ the larger dispersions were in the clear condition and /ʌ/ was in the slow condition with 11-speakers. As can be seen in table 3a, specific vowels for some individuals were more dispersed in the habitual condition, although this was rare. For example PDM7, most of his large dispersions were within the habitual condition with the exception of the three back vowels (2 tense /ɑ/ and /u/, and 1 lax vowel /ʌ/) that showed the largest dispersions in the clear speech condition. Given that he had the lowest speech intelligibility rating by listeners, it was interesting to see that these back vowels were more dispersed in clear speech suggesting that he may be retracting his tongue more in clear speech increasing the distinctiveness of these back vowels. This was also seen for most participants for /u/, suggesting that this PDM7 is making articulatory adjustments similar to other participants who are more intelligible. Kinematic studies using either ultrasound to look at lingual movements or surface electromyography looking at labial and mandibular movements may provide evidence regarding articulatory adjustments.

7.1.4 Vowel Duration Discussion

Intrinsic vowel durations are secondary cues to vowels. Duration ratios are established by dividing the duration of a vowel in different conditions (clear/habitual, slow/habitual) to establish a ratio. A ratio of one or more indicates that the vowel duration in (clear or slow) was longer than that same vowels' duration in the habitual condition. Duration ratios revealed no effect of gender found, which is consistent with Neel (2008). Studies on clear speech (Ferguson & Kewley-Port 2002 &2007; Smiljanic & Bradlow 2008a) reported increases in vowel durations for both tense and lax vowels in clear speech. This study showed that for 7 participants there was no increase in lax vowel durations from the habitual condition. Three of the seven had only one lax vowel that did not show any increase in duration from habitual. There also were four other participants who each had 2 to 4 lax vowels showing no increase from habitual. The study showed that durations increased from the habitual to clear condition. This finding is consistent with other clear speech research that shows an increase in the duration of vowels. Although vowel durations increased in clear speech they did not do so to the same extent as seen in the slow speech condition. The increase in duration perhaps allows more time for the listeners to process the signal.

7.2 Speech Perception Discussion

The purpose of the two perceptual tasks was three fold, first to determine if clear speech would result in more intelligible vowels than slow speech especially for the individuals with PD, second to assess if clear speech mode would increase the overall intelligibility of individuals with PD, and third to determine if individuals can sustain clear speech for a period of time (for the length of a 313 word paragraph). Based on results from both perceptual tasks, some general findings were drawn. First, perceptual judgments by listeners revealed that vowels in clear speech were preferred more for both groups of speakers. The listeners' preference for vowels in clear speech did not differ by vowel type, in that both tense and lax vowels were judged relatively similar. Second, overall speakers' sentence productions in clear speech were judged as more intelligible than in the other speaking conditions, although ratings were lower overall for the PD group. Third, speakers showed a decrease in intelligibility score across their 4 sentences produced, except for the PD participants whose' 4th sentence increase in intelligibility.

7.2.1 Perception Task 1- Condition effects

In perceptual task 1, listeners heard two paired phrases, one from each speaking condition, and made a judgment as to which vowel in the keyword (within the phrase) they preferred. The clear speech vowel productions were most often preferred by listeners for both normal control speakers and speakers with PD, when paired with either habitual or slow speech conditions. Results of perceptual task 1 also showed that the effect size was similar for both tense and lax vowels. The only difference between vowel type was for lax vowels in the paired habitual-slow condition for speakers with PD. Moreover, listeners preferred the lax vowels of the PD group in the slow speech condition only slightly more than the habitual condition. This suggests that slowing the speech of individuals with PD does not perceptually enhance their vowel production to the same degree as clear speech. The vowels in clear speech were preferred most often by listeners, followed by a preference for the slow speech, with the least preference for habitual speech. This is significant since one common speech therapy technique is to slow the rate of speech and theoretically increase a speakers' intelligibility. Such research, by Hammen & Yorkston (1996), examined rate manipulation and showed that, for at least some speakers, decreasing rate results in an increase in intelligibility. The findings of the current study also do not support previous research (Weismer, et al. 2001) that shows decreasing rate of speech increases intelligibility for tense and lax vowels (Tjaden, et al. 2005). Since the habitual-slow paired condition was the only one to show a significant difference between tense and lax vowels only for PD group, we collapsed the vowels for further analyses. These tested whether male and female speakers differed in their use of clear speech, and whether there was a positional bias in the paired judgments.

7.2.2 Perception Task 1-Gender effects

Results for Gender (of the speaker), Group (PD and Normal Control) and Condition (habitual, clear, slow) did not always confirm our hypotheses. The prediction that whenever clear speech was available, listeners would prefer vowels produced in clear speech the majority of the time this was upheld, and when vowels in slow speech was paired with habitual, listeners would prefer slow speech, this was not consistently upheld. The listeners' preference for the clear speech of PD male speakers was significantly smaller than that for the PD females and control speakers.

Thus, compared to the control group and PD females in this study; listeners did not find the PD males as successful in the clear and slow speaking conditions as was predicted. That is, when listeners heard habitual speech paired with either clear or slow, they more often preferred the habitual speech. Nonetheless, there was still a statistically significant difference, as listeners preferred the PD males' clear speech only when paired with the slow speech. This may be reflecting the speech production data from this study that showed that men changed their formant values less than women. This difference requires further research.

For the control participant and female PD participants, listeners preferred the speakers' vowels produced in the clear speech manner that was predicted that is, slow above habitual, and clear above both of those. This was found to be beneficial for PD females more so than for control females: There was a statistically significant difference between PD and control females in the CHHC and CSSC condition. This indicates that the PD females showed more benefit in clear speech than normal females. Clear speech was preferred more often in PD females than in normal females. The predicted preference for clear speech over slow was found for all speakers but with lowest above chance probability found for PD males. This suggests that whenever available for normal and PD female speakers, the listeners preferred vowels in clear speech. For the PD female speakers, the listeners also preferred the slow speech more often than the habitual speech. This preference for slow however, was less than that seen for clear speech.

7.2.3 Perceptual Task 1-Position effect

The ordering of the presentation of paired conditions made a difference, in that the vowel in the predicted condition was preferred more often when presented in the second position of the pair of conditions presented (e.g., in the Habitual-Clear paired condition, Clear was preferred more often than when it was heard in the Clear-Habitual paired condition). These results may indicate that when individuals heard a vowel produced in clear speech after they first heard a less clearly produced vowel (produced in habitual or slow speech) the listeners preferred the vowel produced in clear speech. When listeners heard the clear speech production before a less intelligible production it was still preferred but to a lesser degree. The only exception to the sentence position finding noted above was in habitual-clear paired conditions for the PD group; which showed no position effect. For slow speech condition this second position ordering effect was also true for the PD speakers but not for normal speakers. That is, listeners preferred vowels produced in the slow condition for PD individuals only when they first heard the habitual condition. This position effect was interesting, because one would not expect to see a difference in vowel preference considering that the exact same stimuli pairs were presented, just in a different presentation position. The cause, however for this position effect is requires further investigation since stimuli were counterbalanced.

When examining the combined effects of condition and position, listeners preferred vowels in the predicted conditions for normal control speakers and PD females, and to a lesser degree, PD males. Listeners preferred vowels for the PD males in either the habitual or slow condition. The exception for these participants was when comparing clear and slow, where clear was preferred more often, albeit only slightly above chance. There was no statistically significant difference between the CHHC and the SHHS conditions for the PD males. For the PD females, listeners preferred the predicted vowel in the clear speech conditions (CSSC and CHHC) significantly more often. In the SHHS condition, the predicted slow condition was preferred however, to a much lesser extent then the clear condition. This suggests that, the PD female vowels benefitted more from the clear speech condition than the slow condition. Results for both PD males and PD females imply that slow speech does not increase speech intelligibility as much as previously suspected. Furthermore, considering that past research on PD has not previously incorporated clear speech in their research paradigm, only the effects of slow speech were shown to provide some benefit. However, considering that one characteristic of clear speech is a slow rate, one might also have expected there to be no difference between the outcomes of these two conditions. Still, given that clear speech was preferred more by listeners, results suggest that listeners prefer clear speech because of other characteristics of clear speech may also have been affected when speakers switched speaking modes. This is consistent with theories of Picheny, et al. (1986), although it was consistent other characteristics of clear speech such as changes in pitch and or amplitude; these were beyond the focus of this study and will be examined in future studies.

7.3 Discussion of Perceptual Task 2- Group and Condition Results

Results of Listening task 2, in which entire sentences from different parts of the paragraph were directly rated for intelligibility, indicated that listeners rated the normal control speakers with the exception of (NM4) as having higher intelligibility scores than the PD speakers. This is, of course, entirely as expected. Listeners rated clear speech to be the most intelligible for both groups of speakers. On average, for individuals with PD listeners rated clear speech with the highest intelligibility scores followed by slow speech then habitual speech. More specifically, listeners clearly found the habitual speech of individuals with PD to be least intelligible. That is, speakers with PD increased their intelligibility from their habitual speech, when they changed to clear speech. These results clearly support the need for further research on clear speech instruction and its effect on intelligibility for speakers with PD in a therapeutic protocol. As noted in Figure 12 there were only two exceptions to finding: speakers PDM1 and PDM6 were rated most intelligible in their habitual condition. The reason for these two participants different performance requires additional analysis. Normal individuals, however, showed a slightly different pattern of intelligibility. Listeners also rated clear speech as most intelligible compared to habitual speech and slow speech. There was no difference between habitual speech and slow speech for normal control speakers; this supports previous findings that report that clear speech is more intelligible for normal healthy control individuals (Krause & Braida 2004).

More specifically, for both normal control speakers and PD speakers, the listeners rated the clear speech condition to be most intelligible. As can been seen in Figure 12 four out of four normal control women and three out of four normal control men who had the highest intelligibility scores in the clear condition. Six out of seven PD females and two out of six PD males had their highest intelligibility scores in the clear speech condition. This supports the hypothesis of this study that clear speech would be more intelligible than habitual or slow speech and thus would moreover; increase the speech intelligibility of individuals with PD. One normal male (NM3) and one PD female (PDF2), their most intelligible condition was the slow rate of speech. There were three PD males (PDM1, PDM4, PM6) for whom their habitual condition was most intelligible. For PDM7 habitual and clear speech were rated similarly, and although his intelligibility was the poorest of all participants, his habitual and clear conditions were rated as more intelligible than his slow condition. His habitual speech was rapid, as is often reported for some persons with PD. Nonetheless, slowing his speech down did not increase his intelligibility but, in fact, degraded the intelligibility of his speech; clear speech had no perceptual effect on his speech. Although he did not benefit from speaking in the clear condition, it also did not degrade his intelligibility as the slow condition did. This supports the idea that slowing the rate of speech, although a very common therapy technique for a rapid speaker, is not beneficial for everyone. This finding was also reflected in PMD7's acoustic data: He had the largest vowel space area in his clear speech condition and his dispersions were largest mainly in habitual speech. With the exception of the two back vowels he did not receive any benefit from decreasing his rate of speech. Alternative therapy options for some individuals with PD need to be evaluated in treatment efficiency studies. Slowing down a person's rate cannot in and of itself lead to more intelligible productions as has been conventional wisdom. (Darley, Aranson, & Brown,1975).

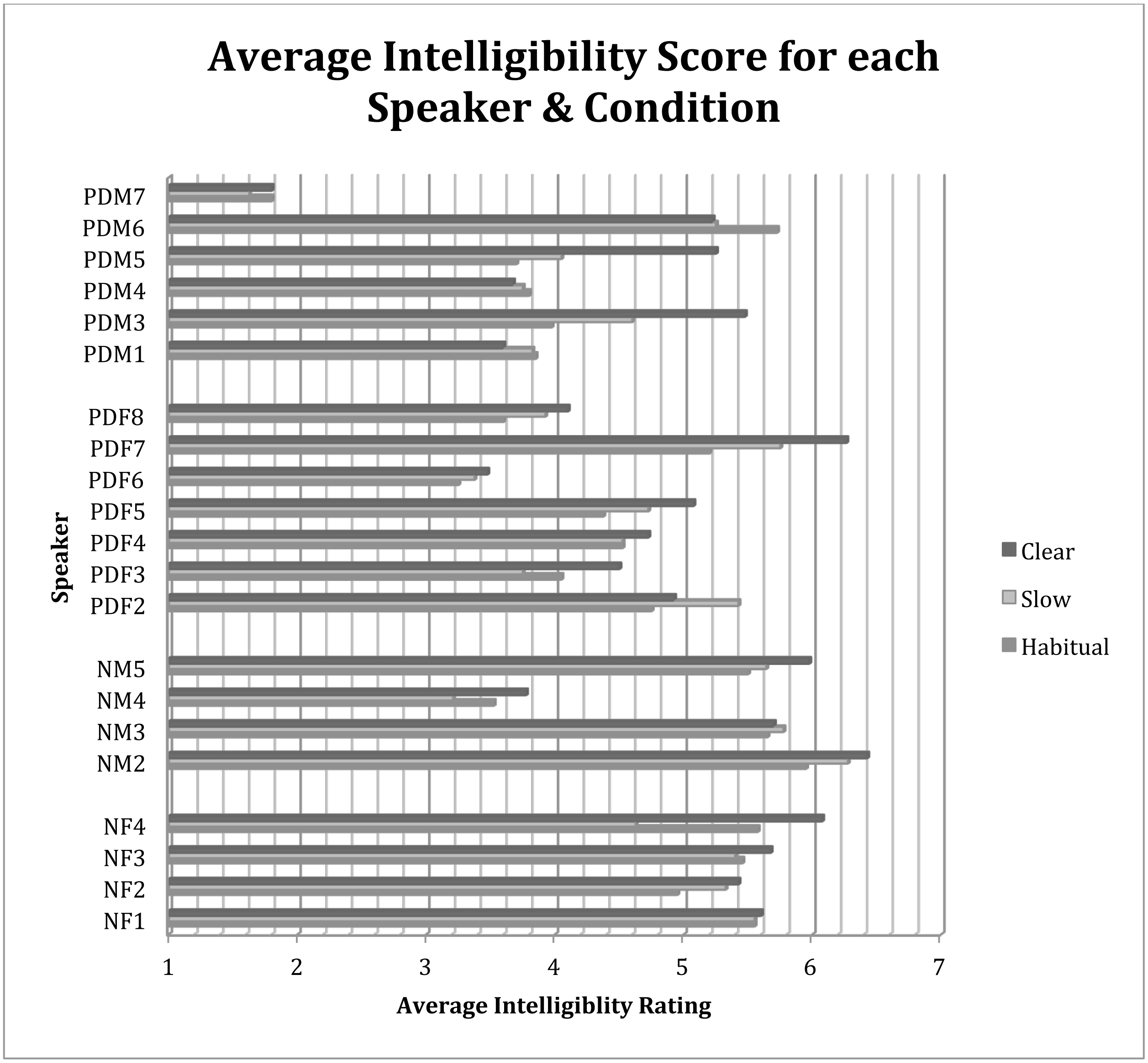


Figure 12. Average Likert scale intelligibility scores (1=least and 7=most intelligible) for each condition (habitual, clear, slow) for each speaker (control and PD). Perceptual Task 2.

7.3.1 Effects of Sentence Position on Intelligibility

The normal control participants' intelligibility scores declined from the initial to final sentence of the paragraph. For the PD group, this same pattern (decline in intelligibility) was seen for sentence 1 to 3; the difference, however, was that the PD increased in intelligibility for sentence four. This suggests that speakers, regardless of group, were not able to sustain the same level of intelligibility within each speaking condition for the first three quarters of the paragraph. The exception was the fourth sentence for the PD speakers, who as previously stated, increased their intelligibility. This suggests that PD speakers made different adjustments in speaking perhaps anticipating the last portion of the paragraph. These might include changes in respiratory control or laryngeal adjustments (Goberman & Elmer 2005; Sapir, Ramig & Fox, 2006) Regardless of group (normal or PD) the females were rated more intelligible than the males for the 4 sentences. This is consistent with Ferguson (2004), normal females were more intelligible than males in clear speech. The second sentence was significantly different for females and males when compared to sentence 1: The females' sentence 2 was just as intelligible as sentence 1, and the males' second sentence was statistically significantly less intelligible then the first sentence. This finding partially supports Smiljanic & Bradlow (2008b), who found that regardless of gender when "individuals read a shorter paragraph (112 words) they did not sustain the clear speech mode, but in the longer paragraph they did (212 words), even then the distribution of sentence intelligibly was not consistent" (p.3176-7). That is the portions of the shorter paragraph were not rated as intelligible as the longer paragraph. The paragraph in the current study was 313 monosyllabic words, which is longer than the paragraph in Smiljanic & Bradlow (2008b), which may explain the difficulty people had in sustaining intelligibility. It would be of interest to see if perhaps with training, if individuals could be taught to sustain a speaking mode for a period of time. Again, this would be of interest for a future clinical study.

7.4 Conclusion

The results of both the speech production and perception sections of this study indicated that most individuals both those with PD and controls benefitted from clear speech mode. In the acoustic analysis we found that clear speech increased vowels space areas, increased /i-ɑ/

distances, increased dispersions for some vowels, and also increased vowel duration (although durations were longer in slow speech). Perceptually, listeners preferred vowels in the clear speech condition overall when compared to other conditions for both groups of speakers, as seen in perceptual task 1 with no preference for vowel type (tense or lax). In perceptual task 2, clear speech had the highest intelligibility scores for 15 out of 21 individuals (8 out of 13 PD and 7 out of 8 normal control). Four out of 13 individuals with PD had their highest intelligibility scores in their habitual speech. This may be due to variability in the PD participant dysarthria rating: participants were rated as having mild to moderate dysarthria, with the exception of PDM7 who was the only participant rated with severe dysarthria. For PDM7 whose highest intelligibility score was in habitual and clear speech. Finally, for 2 out of 21 individuals (PDF2 and NM3) had their highest intelligibility scores in the slow speech condition. When examining both speech production and speech perception data combined, it was observed that for 3 out of 8 normal healthy individuals (NF1, NF3, NM3) and 4 out of 13 individuals with PD (PDF3, PDF7, PDM3, PDM5) all had both their largest vowel space area for tense vowels and largest /i-ɑ/ distance in the clear speech condition. For these same individuals their highest intelligibility scores were in the clear speech conditions. The only other participant to show the same consistency between production and perception was PDM4, his largest vowel space area for tense vowels and /i-ɑ/ distance and most intelligibility rating was in the habitual speech condition. The relationship of the acoustic with perceptual preference makes it imperative that both be studied, rather than assuming that acoustic differences are necessarily perceptually relevant.

Appendix 1
The Farm Passage

John and I went to the farm in June. (*The sun shone all day, and wind waved the grass in wide fields that ran by the road).* Most birds had left[1] on their trek south, but old friends were there to greet us. Piles of wood[1] had been stacked by the door, left there by the man who lives[1] twelve miles down the road. *The stove would not last[1] till dawn on what[1] he had cut[2], so I went and chopped[1] more till the sun set[2].* The sky stays light quite late as far north as that[2], but I knew it would be a cold night. The car seat[1] was piled high with stuff, but it would have to stay there for the night. It was too far to go to take it all out now. (Food[1] was the next[3] thing. *John had lit[2] the stove, so I cooked[3] up[3] some hash[3] and beans, which was what[4] was in the cans that I could reach with the least work).* My box[2] with most of the food[2] was deep[2] in the car, and it was too dark now to dig my way down to it. When served hot[3], hash[4] and beans taste quite good[2] if it's been a long time since you last[5] ate. We had some bread, of a sort that you find in small stores far from the towns, where the new ways to make bread, and the new types of flour have not yet[4] reached. We had passed[6] such a place on the road, and had stocked up[5] with some things that can't be bought in a town.) (*Things like home baked bread; and real cheese[3] made from cow's milk; jam with real fruit[3] in it; and fresh milk with rich[3] deep[4] cream on top[4].*) We shall not have a chance to buy these[5] in the cold months that are to come.

= Indicates Lax vowels

Sentences in italics were those used in perception task 2.

Appendix 2
Speech Production ANOVA tables

ANOVA (FULL) -Vowel Space Area

. anova score group gender group#gender / id|group#gender ///
> cond group#cond gender#cond group#gender#cond / cond#id|group#gender ///
> vowel group#vowel gender#vowel group#gender#vowel / vowel#id|group#gender ///
> cond#vowel group#cond#vowel gender#cond#vowel group#gender#cond#vowel/, repeated(cond vowel)

Number of obs=126, R-squared = 0.9931, Root MSE= 22029.5, Adj R-squared=0.9747

Model	2.3822e+12	91	2.6178e+10	53.94	0.0000
group	8.2593e+09	1	8.2593e+09	0.50	0.4882
gender	2.2744e+11	1	2.2744e+11	13.83	0.0017
group#gender	832743187	1	832743187	0.05	0.8247
id|group#gender	2.7965e+11	17	1.6450e+10		
cond	1.4375e+10	2	7.1873e+09	6.26	0.0048
group#cond	913194661	2	456597331	0.40	0.6748
gender#cond	436386016	2	218193008	0.19	0.8277
group#gender#cond	794762621	2	397381311	0.35	0.7098
cond#id|group#gender	3.9018e+10	34	1.1476e+09		
vowel	1.5296e+12	1	1.5296e+12	241.83	0.0000
group#vowel	1.3755e+09	1	1.3755e+09	0.22	0.6469
gender#vowel	6.7669e+10	1	6.7669e+10	10.70	0.0045
group#gender#vowel	9476837.18	1	9476837.18	0.00	0.9696
vowel#id|group#gender	1.0753e+11	17	6.3252e+09		
cond#vowel	3.6874e+09	2	1.8437e+09	3.80	0.0324
group#cond#vowel	254542170	2	127271085	0.26	0.7709
gender#cond#vowel	64260361.9	2	32130181	0.07	0.9361
group#gender#cond#vowel	59285098.5	2	29642549.3	0.06	0.9408
Residual	1.6500e+10	34	485298251		
Total	2.3987e+12	125	1.9190e+10		

ANOVA(FULL) /i-ɑ/ Distances

```
. *
full
. anova score2  group gender group#gender / id|group#gender   ///
> cond group#cond gender#cond group#gender#cond , repeated(cond)

                           Number of obs =      63     R-squared     = 0.9578
                           Root MSE      = 56.5637     Adj R-squared = 0.9230

                  Source |  Partial SS    df       MS           F    Prob > F
       ------------------+----------------------------------------------------
-
                   Model |  2468402.88    28  88157.2457      27.55    0.0000
                         |
                   group |   39834.334     1   39834.334       0.70    0.4131
                  gender |  1400813.75     1  1400813.75      24.75    0.0001
            group#gender |  6680.85125     1  6680.85125       0.12    0.7354
         id|group#gender |   962123.59    17  56595.5053
       ------------------+----------------------------------------------------
                    cond |  41483.4361     2   20741.718       6.48    0.0041
              group#cond |  11292.3928     2  5646.19641       1.76    0.1866
             gender#cond |  1134.42036     2  567.210181       0.18    0.8383
       group#gender#cond |  1633.65027     2  816.825136       0.26    0.7762
                         |
                Residual |  108781.564    34  3199.45776
       ------------------+----------------------------------------------------
-
                   Total |  2577184.44    62   41567.491
```

ANOVA- Vowel Dispersions

```
 * full[gender,group,cond,vowel8] (only stata se)
. anova score              group gender group#gender / id|group#gender   ///
>       cond group#cond gender#cond group#gender#cond / cond#id|group#gender   ///
cond#vowel8 group#cond#vowel8 gender#cond#vowel8 group#gender#cond#vowel8/,
   ➢     repeated(cond vowel8) dropemptycells
   ➢

                           Number of obs =     504     R-squared     =  0.9843
                           Root MSE      = 36.0195     Adj R-squared =  0.9668

                  Source |  Partial SS    df       MS           F     Prob > F
  -----------------------+----------------------------------------------------
                   Model |  19374489.9   265  73111.2825      56.35     0.0000
                         |
                   group |  53525.2341     1  53525.2341       0.72     0.4088
                  gender |  806430.616     1  806430.616      10.81     0.0043
            group#gender |  19825.4762     1  19825.4762       0.27     0.6129
         id|group#gender |  1268576.09    17  74622.1227
  -----------------------+----------------------------------------------------
                    cond |    45800.76     2    22900.38       5.81     0.0068
              group#cond |   3435.1455     2  1717.57275       0.44     0.6504
             gender#cond |  292.332498     2  146.166249       0.04     0.9636
       group#gender#cond |  8282.78905     2  4141.39453       1.05     0.3609
    cond#id|group#gender |  134057.075    34  3942.85513
  -----------------------+----------------------------------------------------
                  vowel8 |  14463034.1     7  2066147.73     165.64     0.0000
            group#vowel8 |  89009.4823     7  12715.6403       1.02     0.4212
           gender#vowel8 |  182661.703     7   26094.529       2.09     0.0495
     group#gender#vowel8 |  7537.31928     7   1076.7599       0.09     0.9989
  vowel8#id|group#gender |  1484399.21   119  12473.9429
  -----------------------+----------------------------------------------------
             cond#vowel8 |   46305.254    14  3307.51814       2.55     0.0020
       group#cond#vowel8 |  17545.7851    14  1253.27036       0.97     0.4890
      gender#cond#vowel8 |  15189.5284    14  1084.96631       0.84     0.6292
      group#gender#cond# |
                  vowel8 |   23704.133    14  1693.15235       1.31     0.2049
                         |
                Residual |  308781.569   238  1297.40155
  -----------------------+----------------------------------------------------
                   Total |  19683271.4   503  39131.7524
```

ANOVA (FULL) Duration Ratios

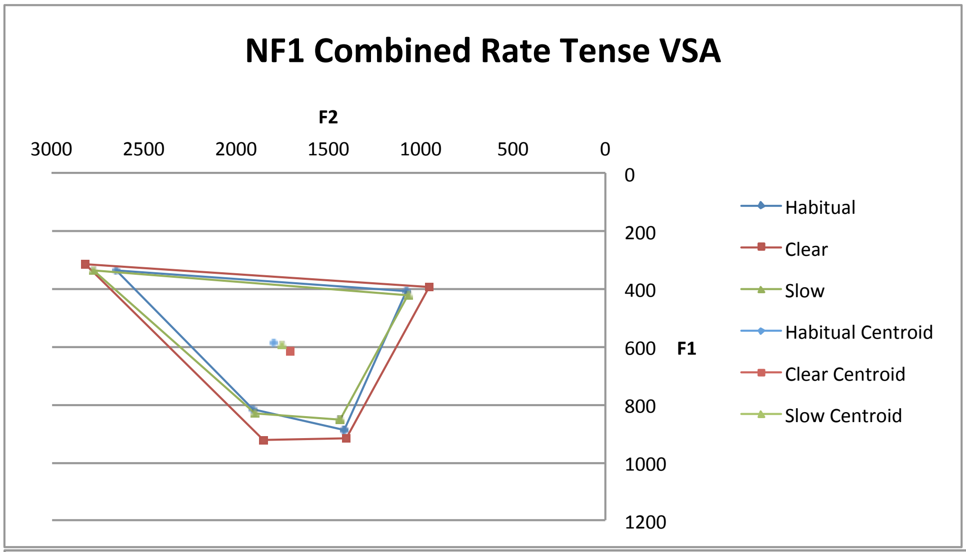
```
. * full[gender,group,cond,vowel8] (only stata se)
. anova score               group gender group#gender / id|group#gender
///
cond group#cond gender#cond group#gender#cond / cond#id|group#gender   ///
>vowel8 group#vowel8 gender#vowel8 group#gender#vowel8 / vowel8#id|group#gender
/// cond#vowel8 group#cond#vowel8 gender#cond#vowel8 group#gender#cond#vowel8/
, repeated(cond vowel8) dropemptycells
```

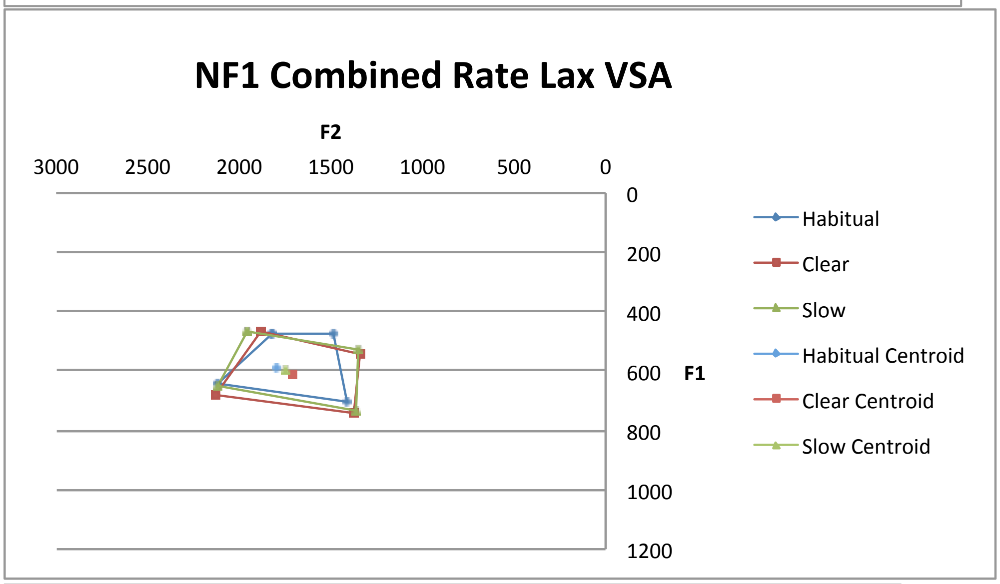
```
                          Number of obs =     336     R-squared     =  0.8903
                          Root MSE      = .110985     Adj R-squared =  0.6911

                  Source |  Partial SS    df       MS           F     Prob > F
  -----------------------+----------------------------------------------------
                   Model |  11.8944488   216  .055066893       4.47     0.0000
                         |
                   group |  .223113657     1  .223113657       1.16     0.2959
                  gender |  .001165957     1  .001165957       0.01     0.9388
            group#gender |  .000736073     1  .000736073       0.00     0.9513
         id|group#gender |  3.26067424    17  .191804367
  -----------------------+----------------------------------------------------
                    cond |  .254252819     1  .254252819       2.92     0.1058
              group#cond |  .068111074     1  .068111074       0.78     0.3889
             gender#cond |  .047421932     1  .047421932       0.54     0.4707
       group#gender#cond |   .00199911     1   .00199911       0.02     0.8814
    cond#id|group#gender |  1.48096062    17  .087115331
  -----------------------+----------------------------------------------------
                  vowel8 |  1.64254285     7  .234648979       6.90     0.0000
            group#vowel8 |  .183371907     7  .026195987       0.77     0.6129
           gender#vowel8 |  .298038604     7  .042576943       1.25     0.2798
     group#gender#vowel8 |   .04466815     7  .006381164       0.19     0.9875
  vowel8#id|group#gender |  4.04430513   119  .033985757
  -----------------------+----------------------------------------------------
             cond#vowel8 |  .205106113     7  .029300873       2.38     0.0260
       group#cond#vowel8 |  .077197672     7  .011028239       0.90     0.5126
      gender#cond#vowel8 |  .139519558     7  .019931365       1.62     0.1367
      group#gender#cond# |
                  vowel8 |  .111456781     7  .015922397       1.29     0.2598
                         |
                Residual |  1.46581034   119  .012317734
  -----------------------+----------------------------------------------------
                   Total |  13.3602592   335  .039881371
```

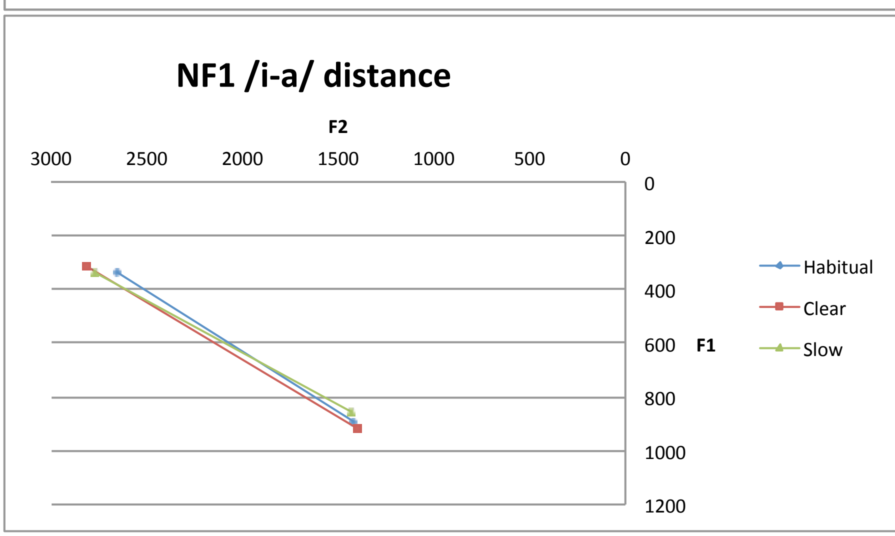
Appendix 3.
Plots of Speech Production Measures for Each Participant

Note in the legend for the vowel plots below that:
Tense vowels: /a/ is for the /ɑ/ phoneme in American English
/ae/ is for the /æ/ phoneme in American English
/i/ is for the /i/ phoneme in American English
/u/ is for the /u/ phoneme in American English

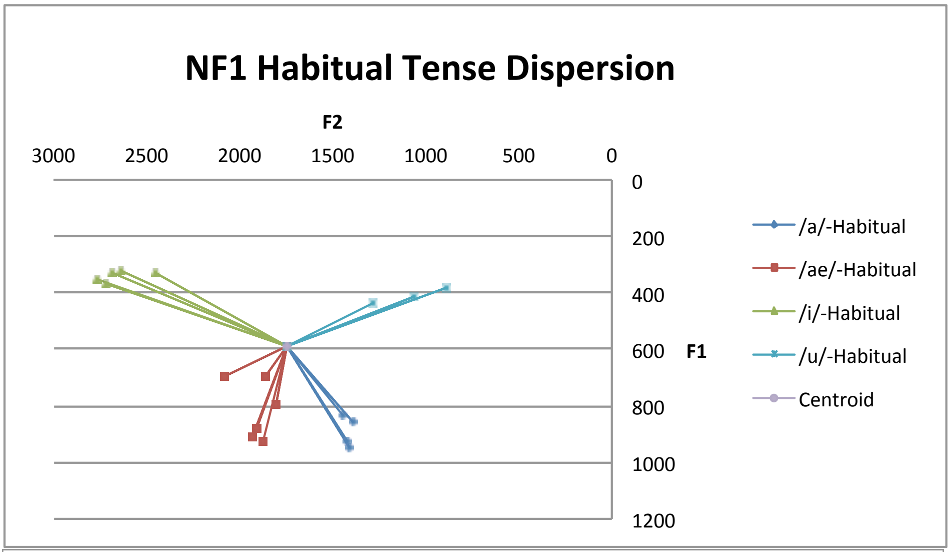
Lax vowels: /ih/ is for the /ɪ/ phoneme in American English
/oo/ is for the /ʊ/ phoneme in American English
/eh/ is for the /ɛ/ phoneme in American English
/uh/ is for the /ʌ/ phoneme in American English

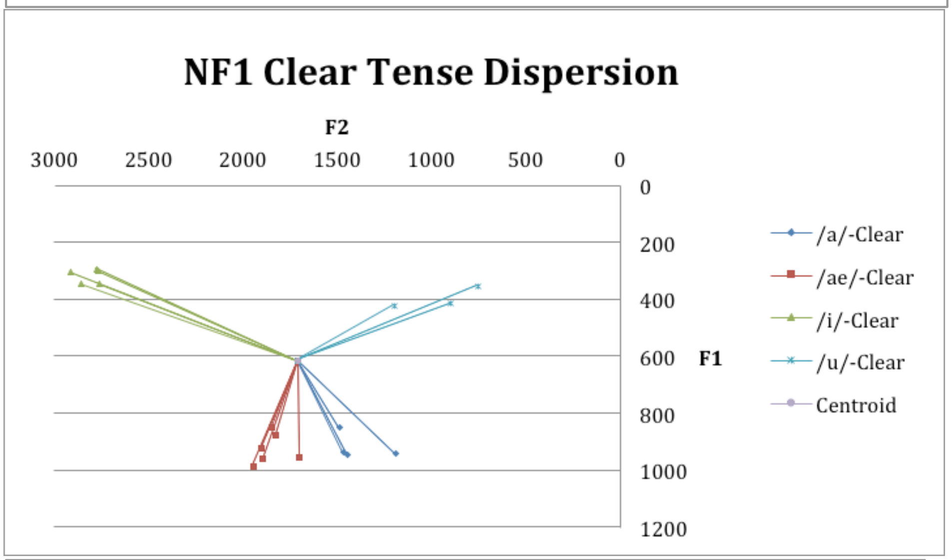


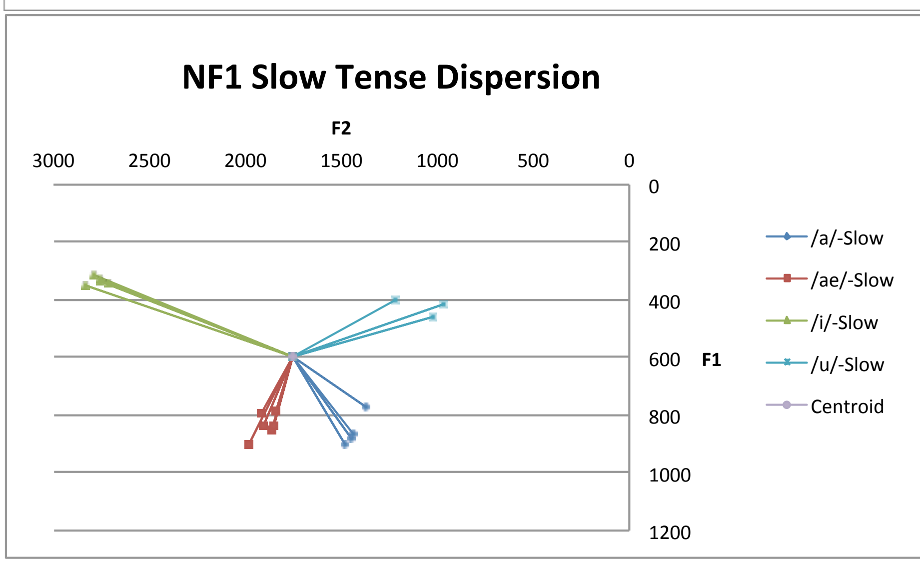




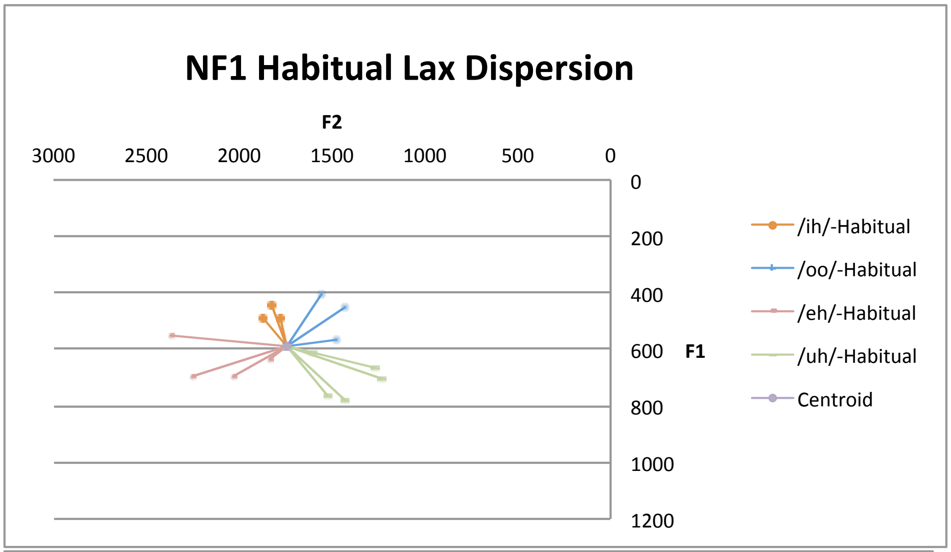
Normal Female 1 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

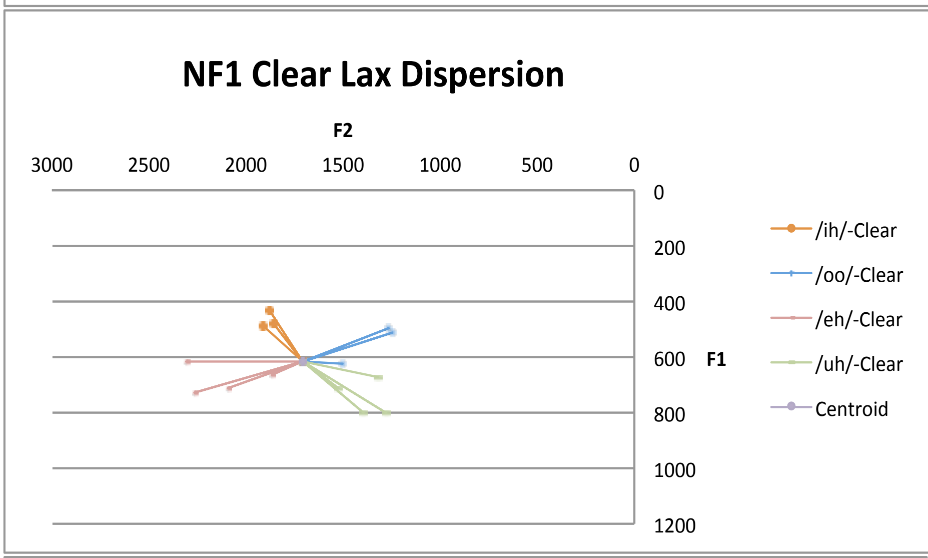


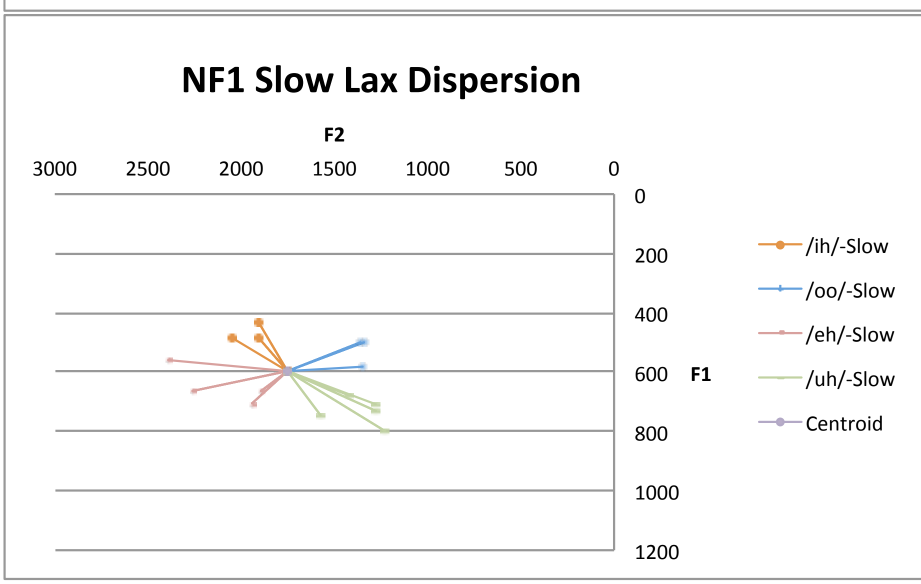




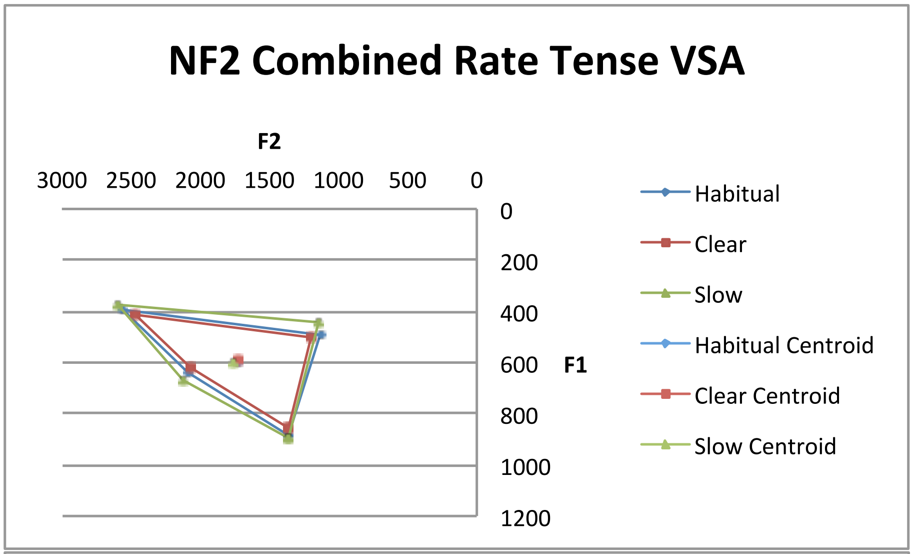
Normal Female 1 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow)

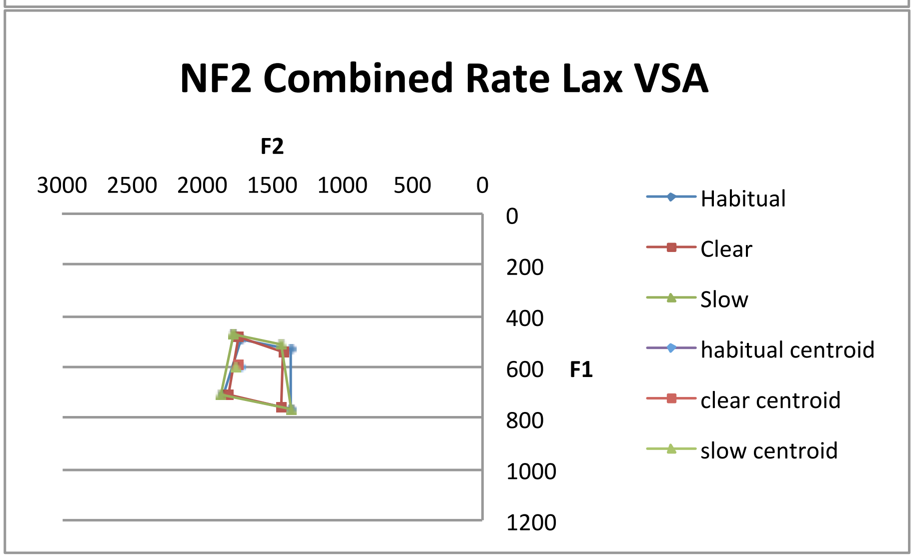


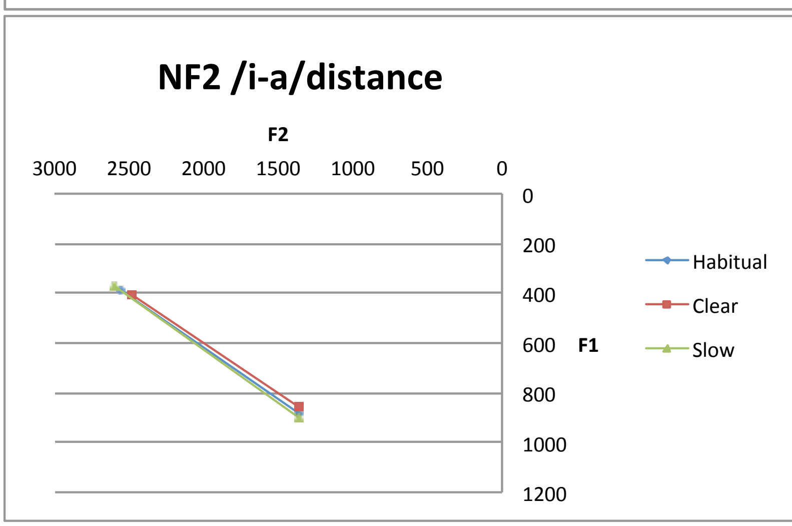




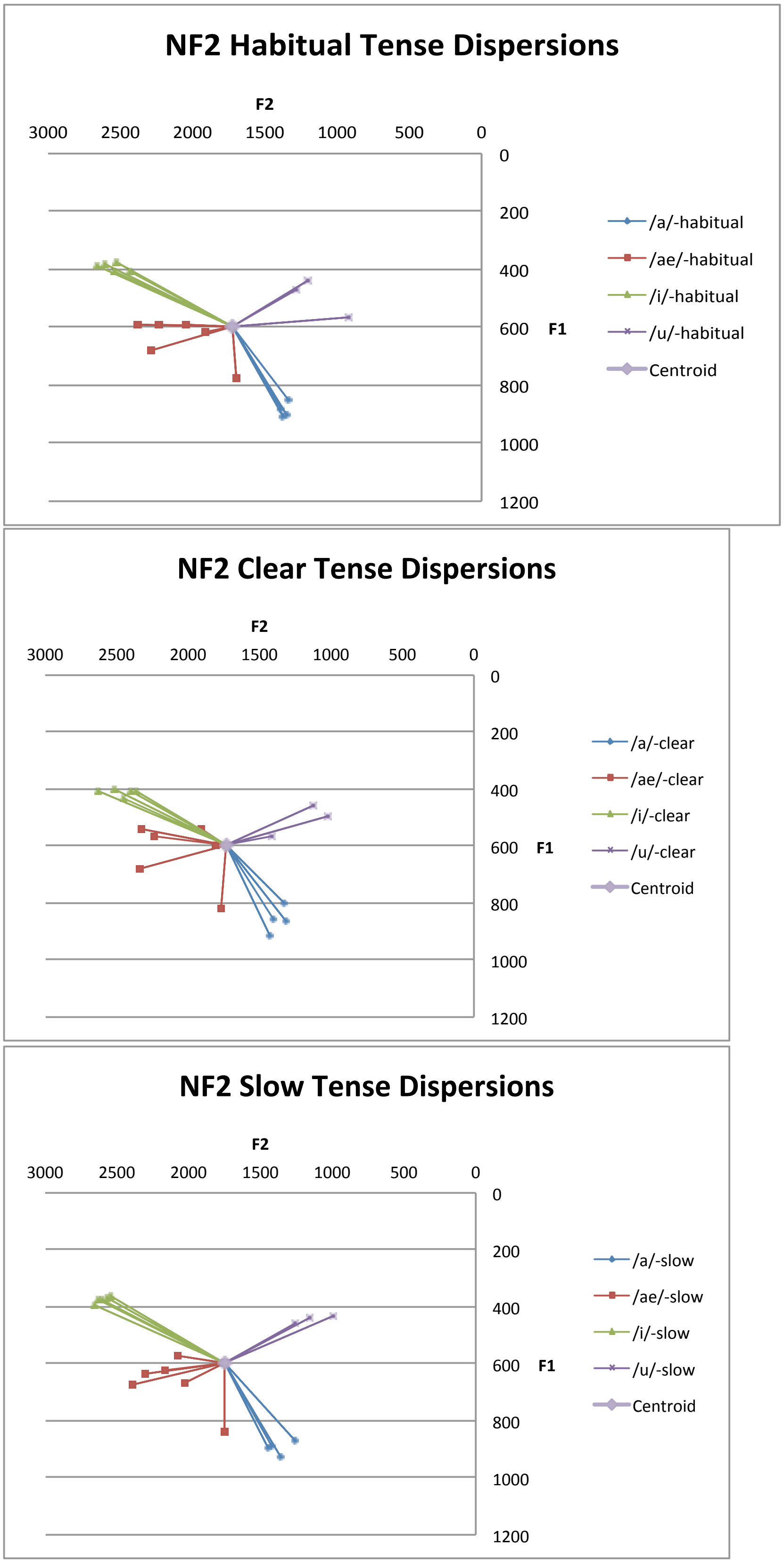
Normal Female 1 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow)



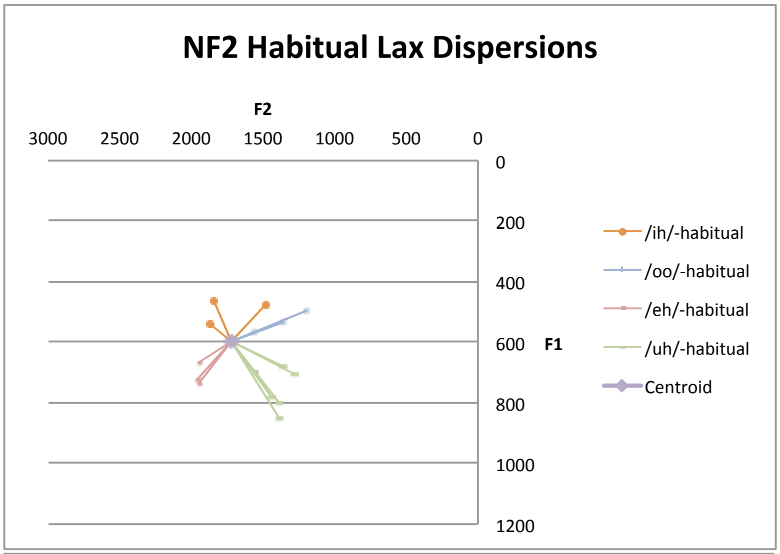


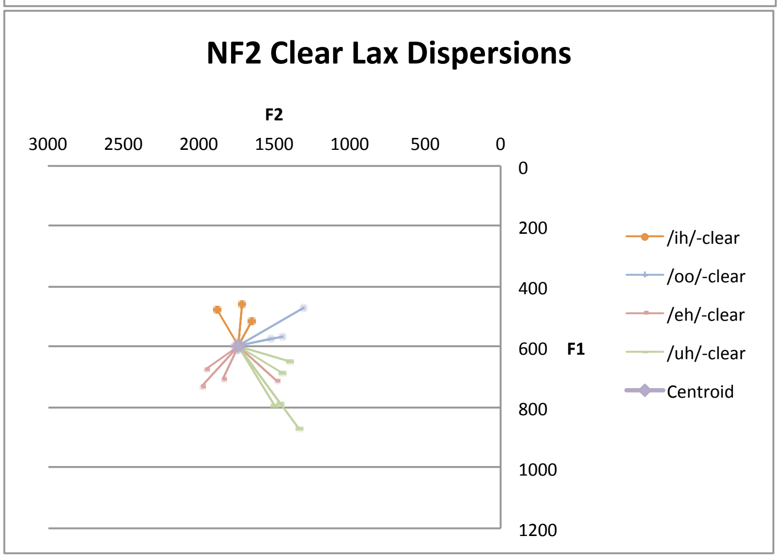


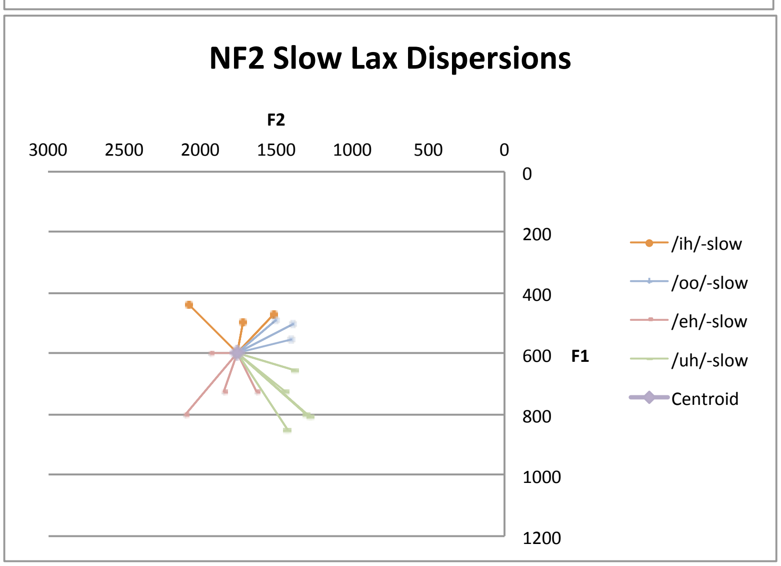
Normal Female 2 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.



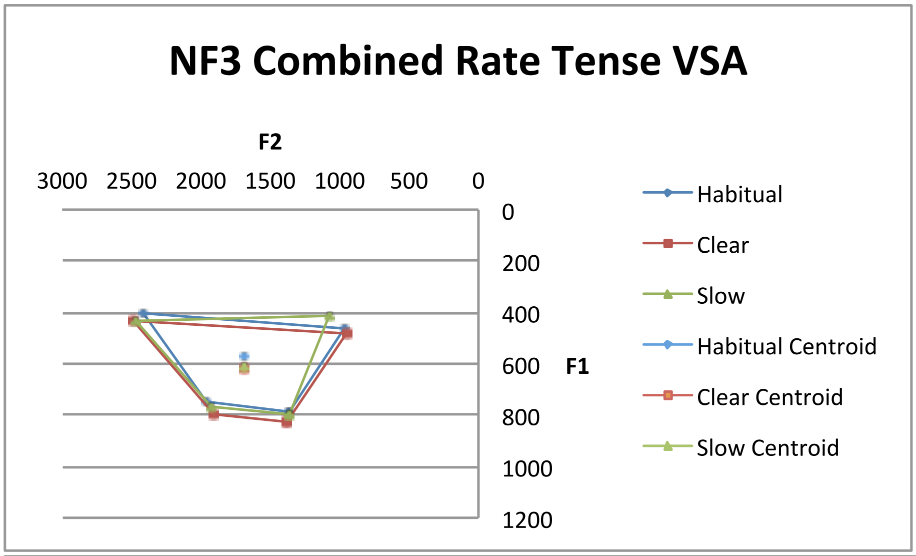
Normal Female 2 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

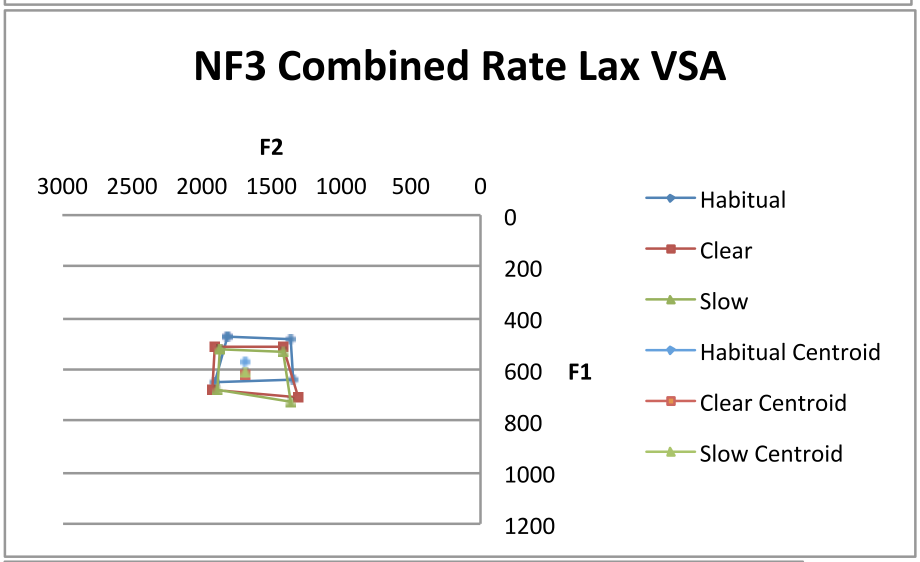


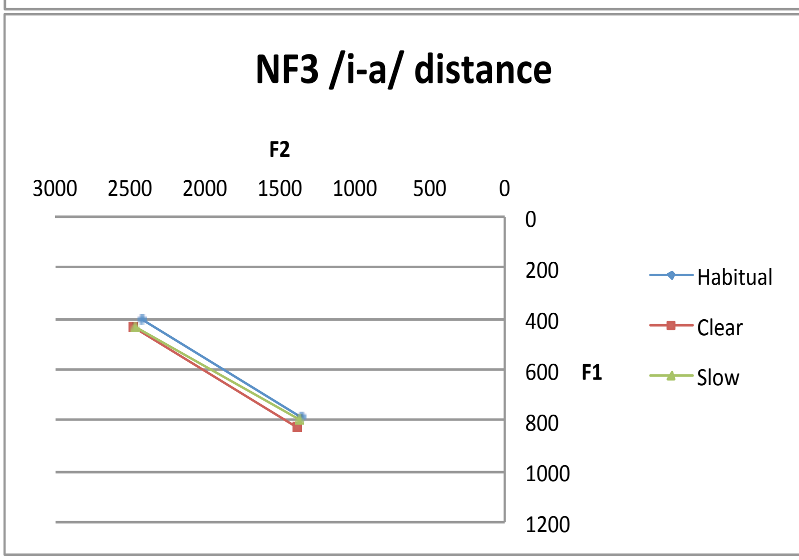




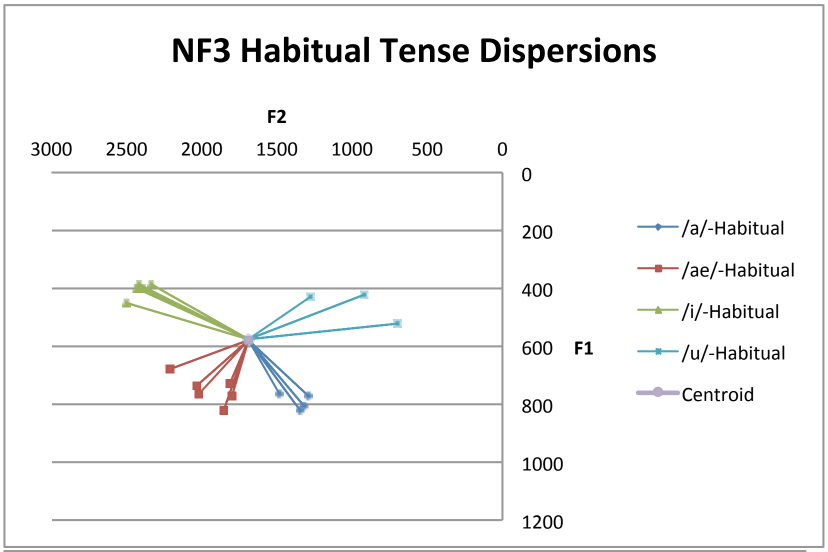
Normal Female 2 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

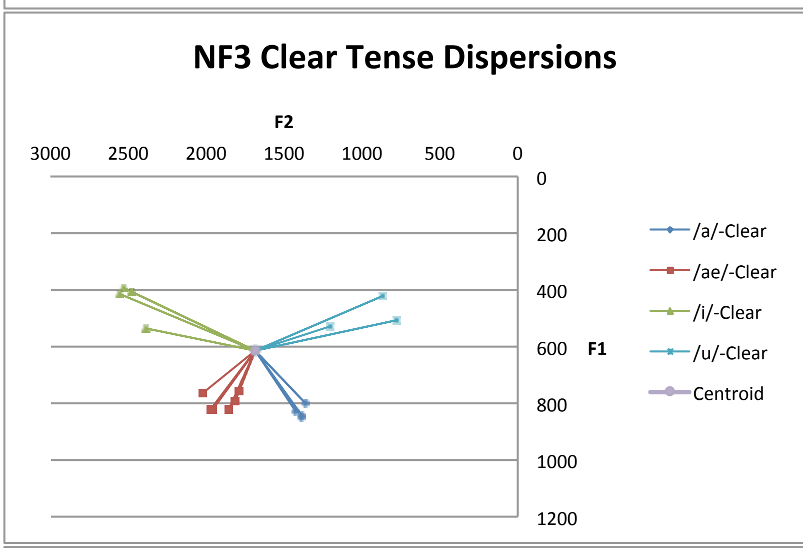


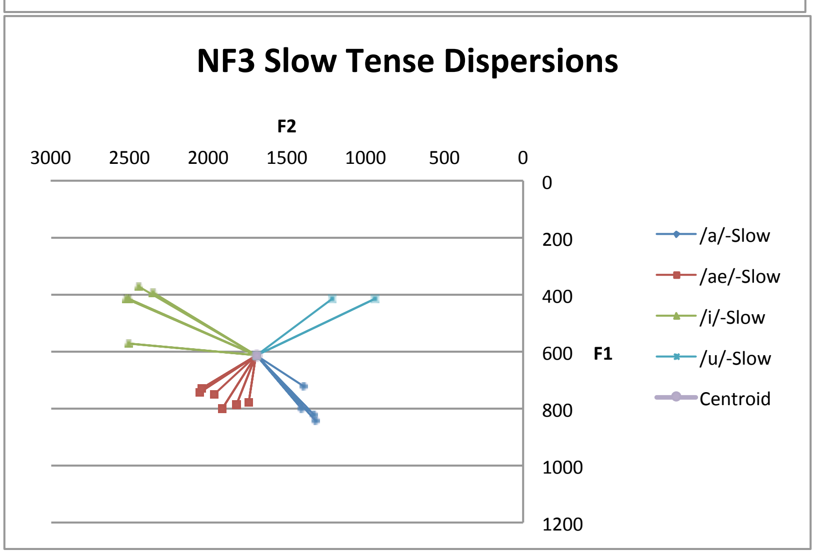




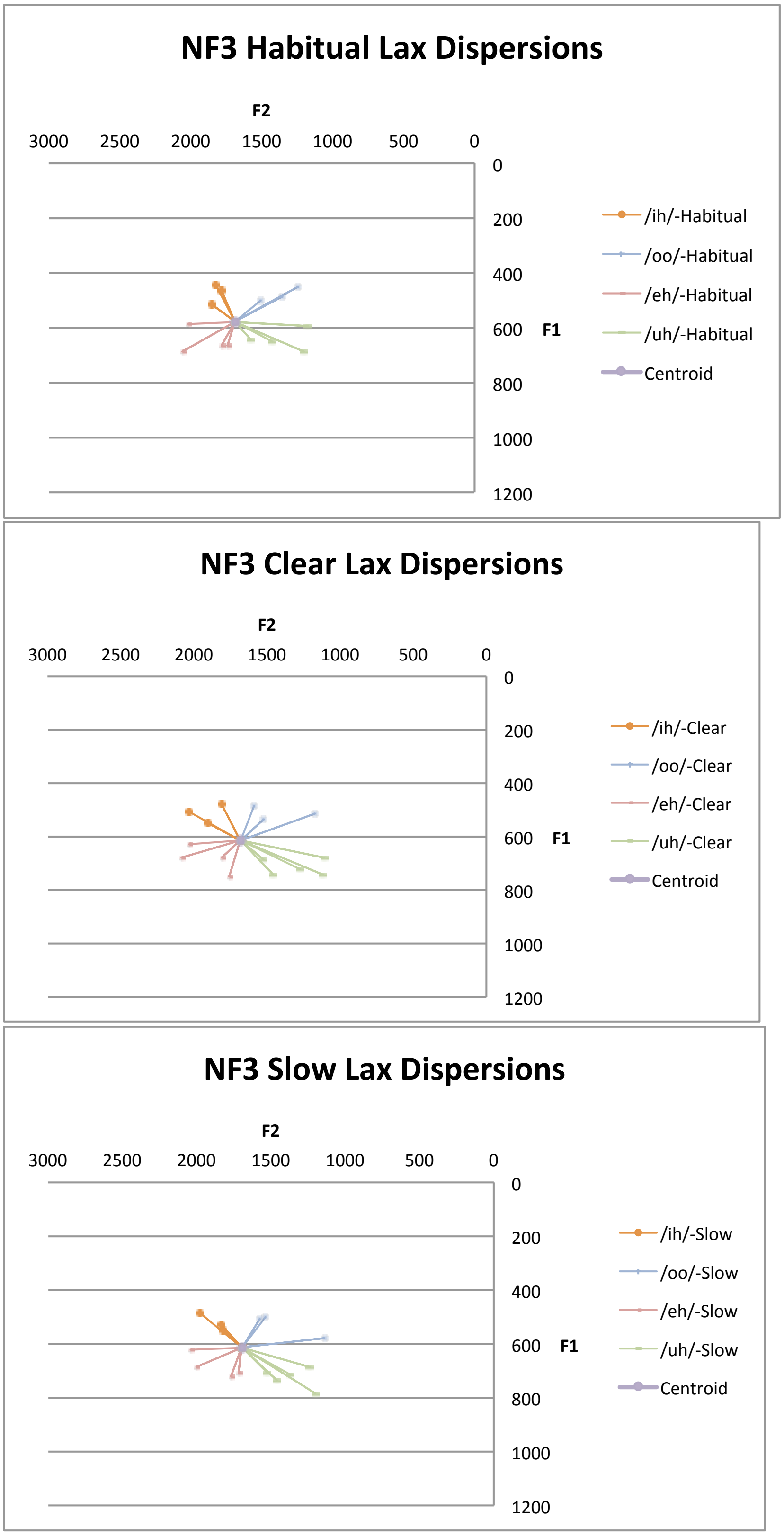
Normal Female 3 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.



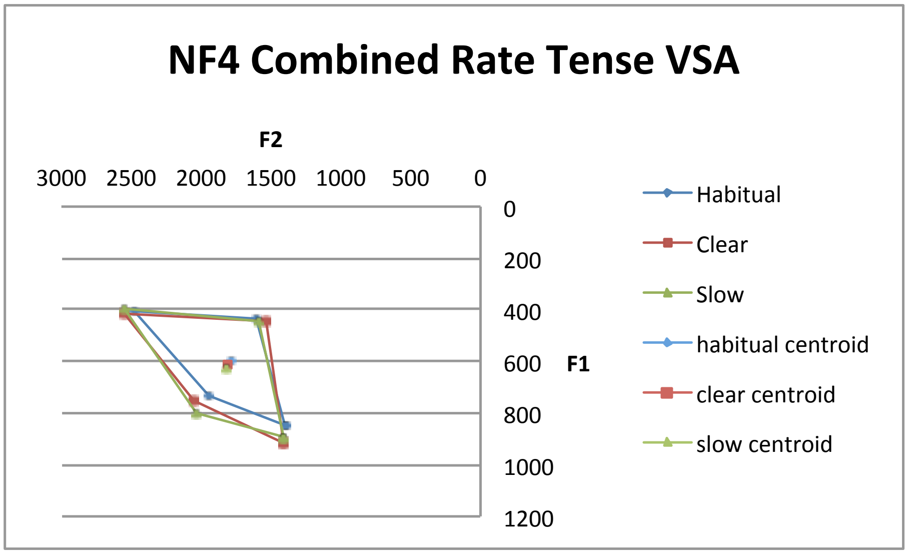


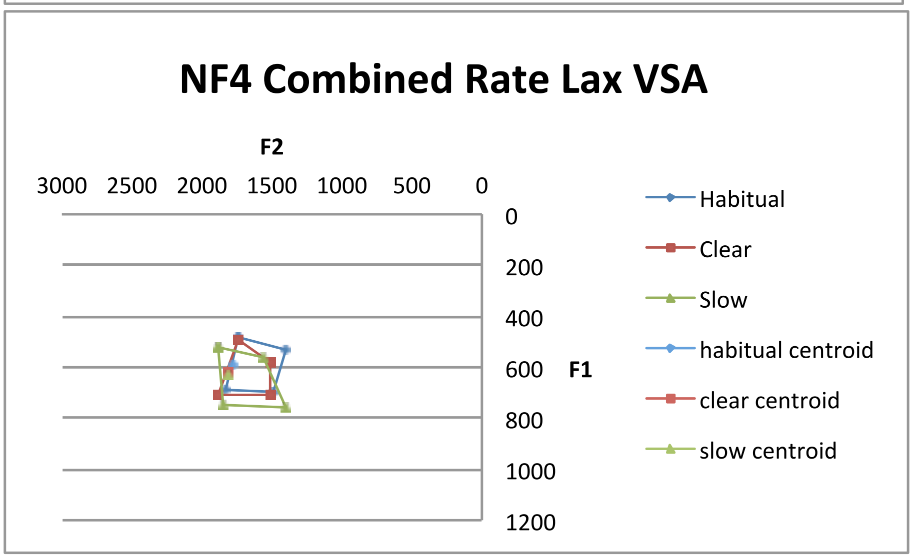


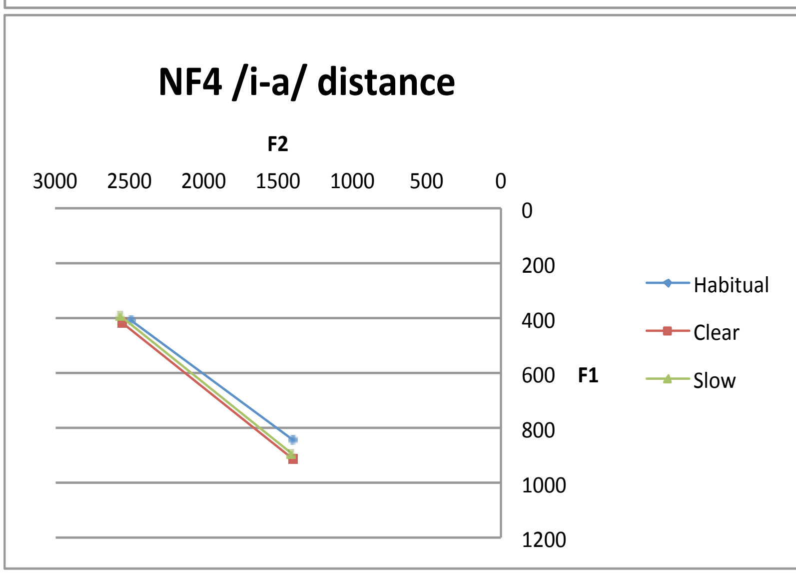
Normal Female 3 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).



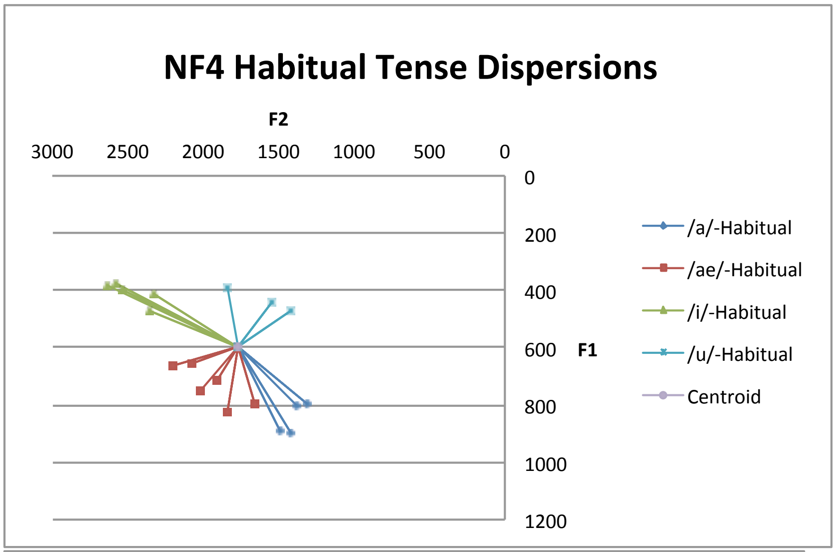
Normal Female 3 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

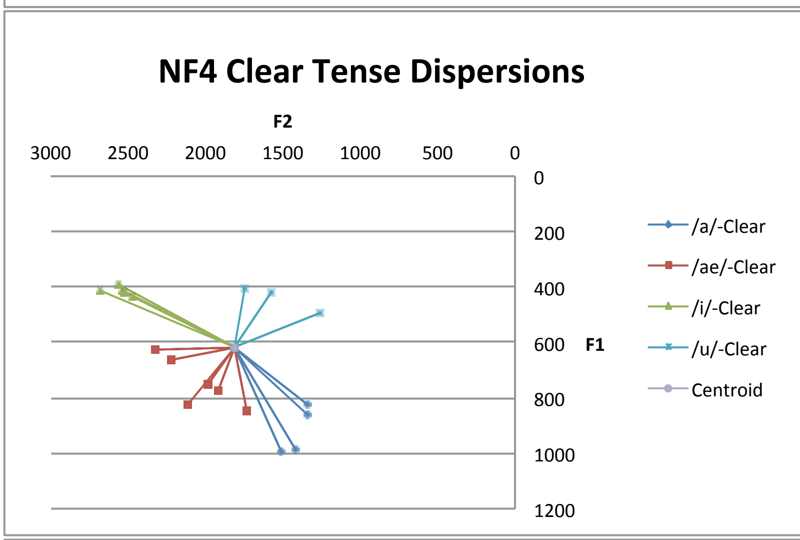


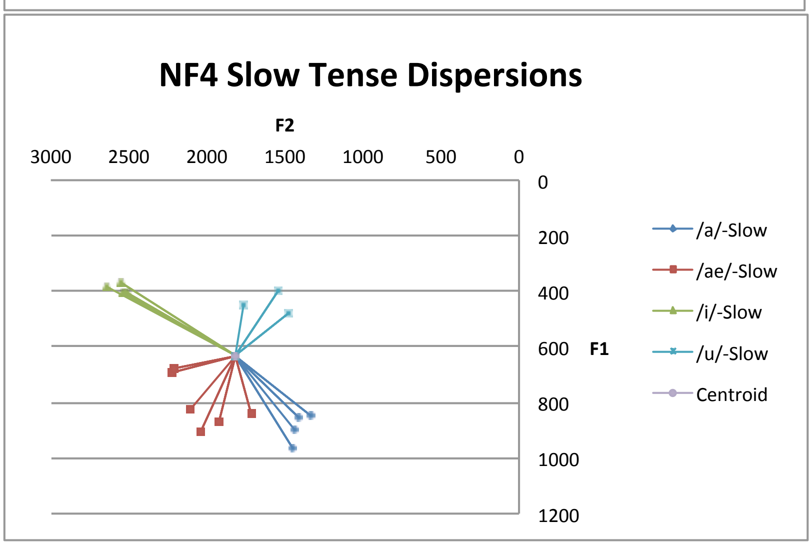




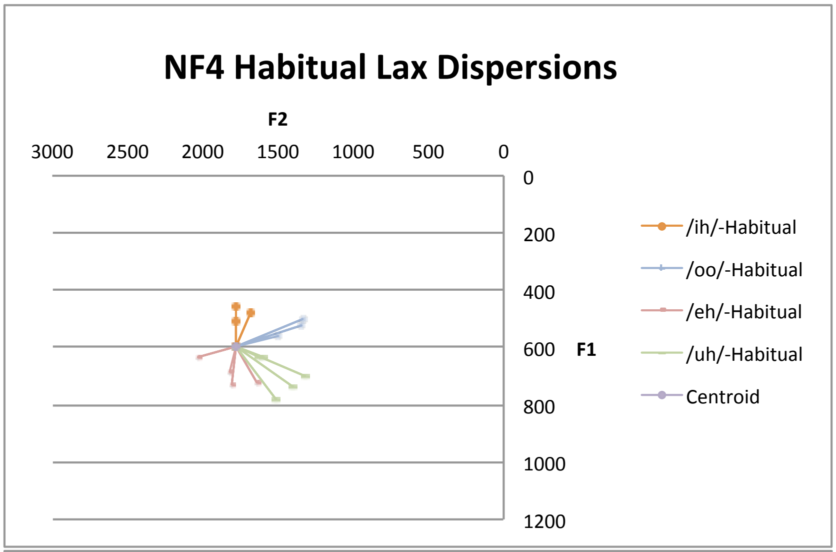
Normal Female 4 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

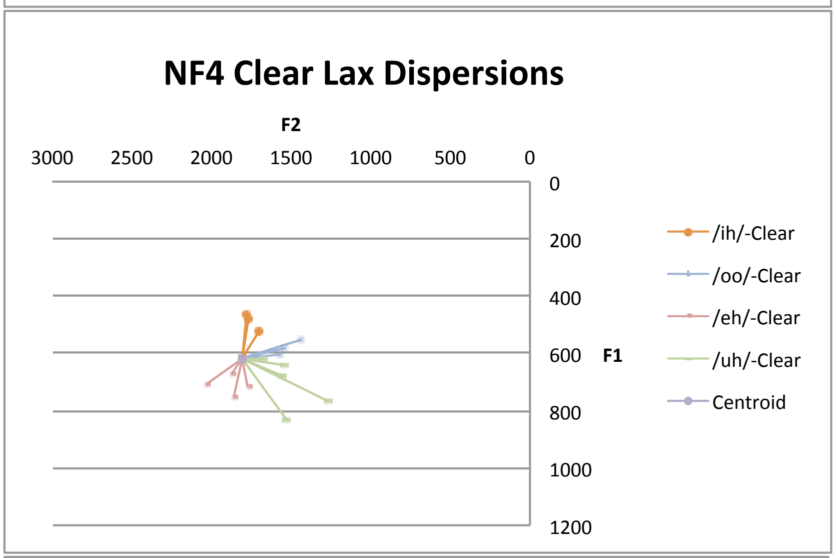


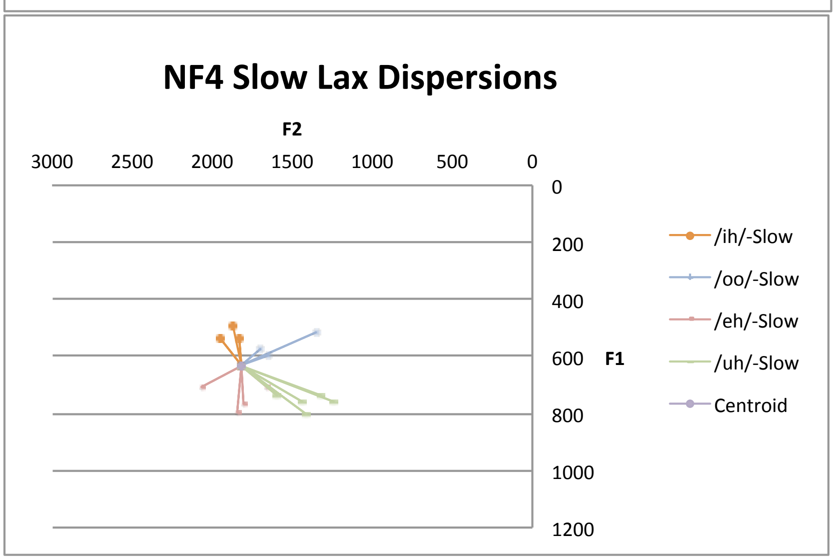




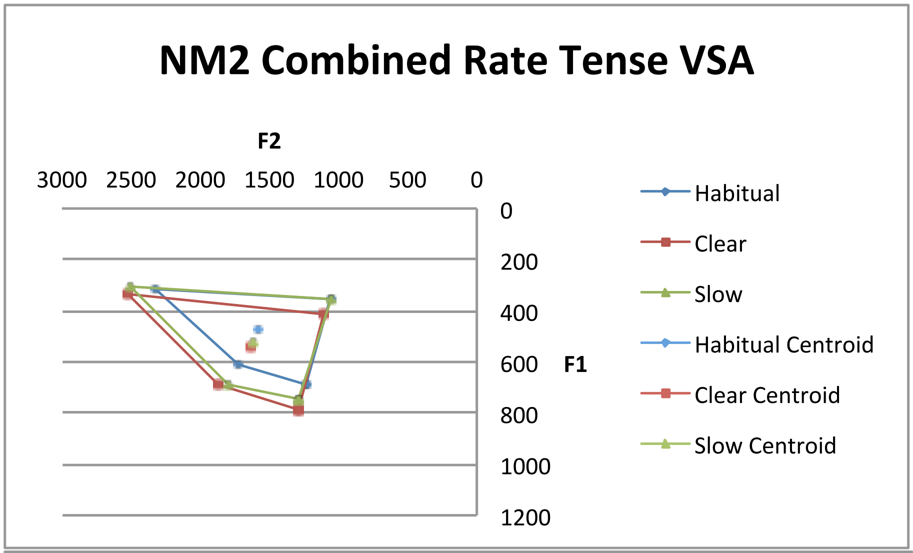
Normal Female 4 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

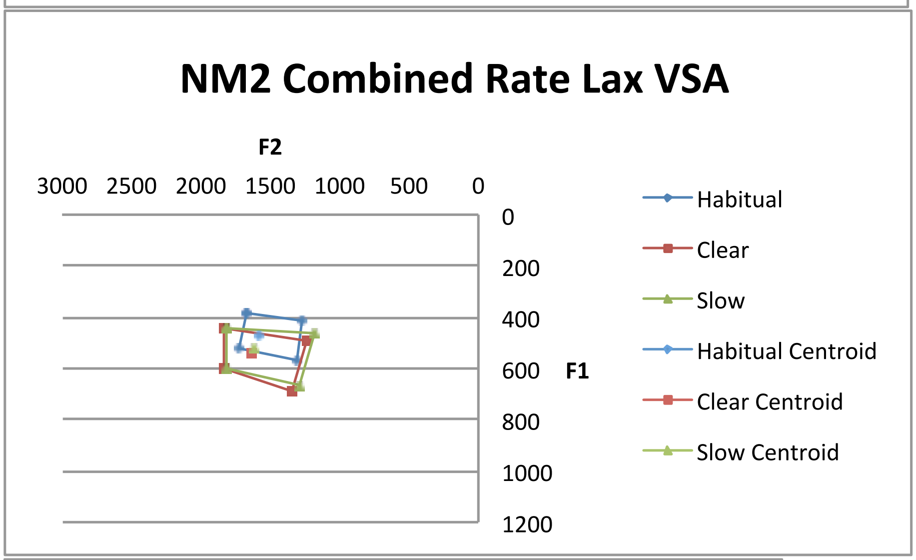


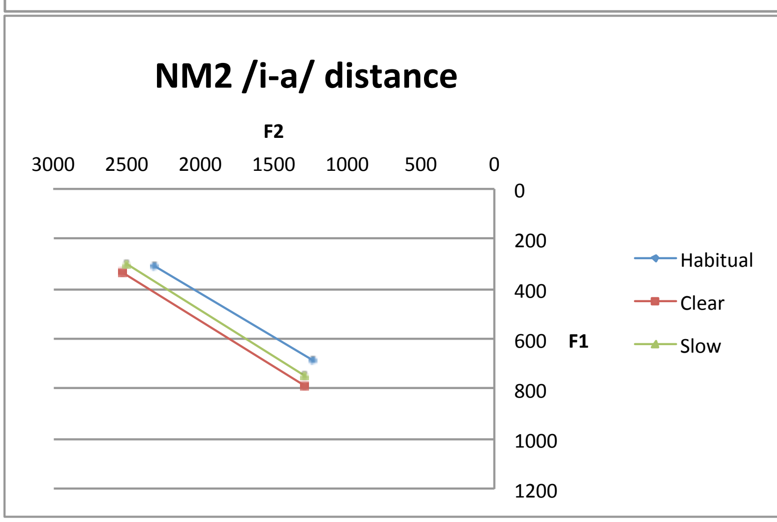




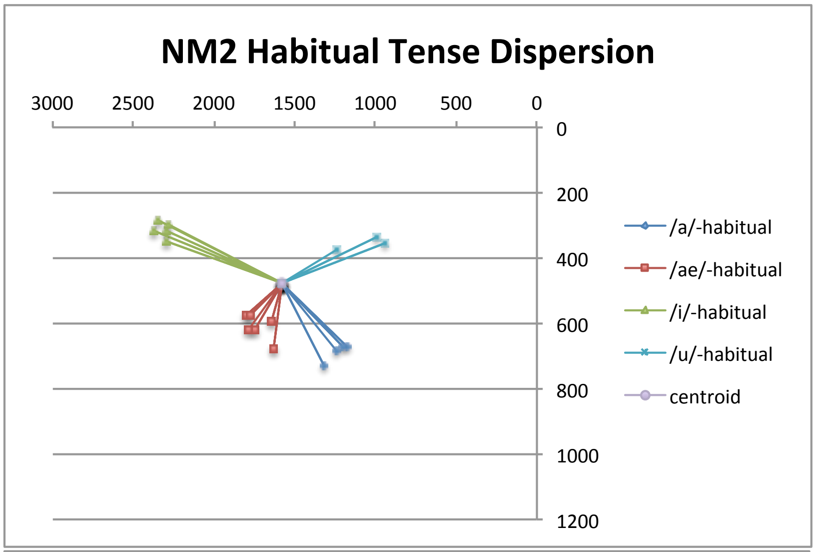
Normal Female 4 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

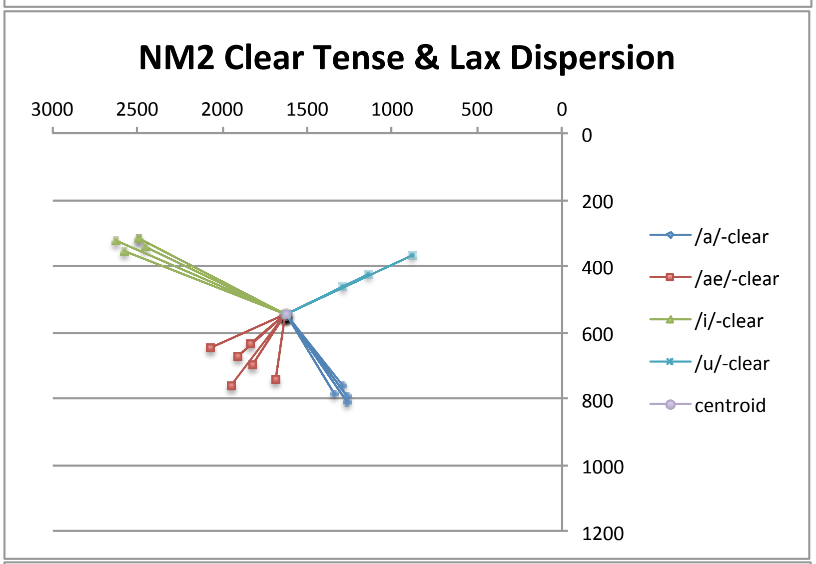


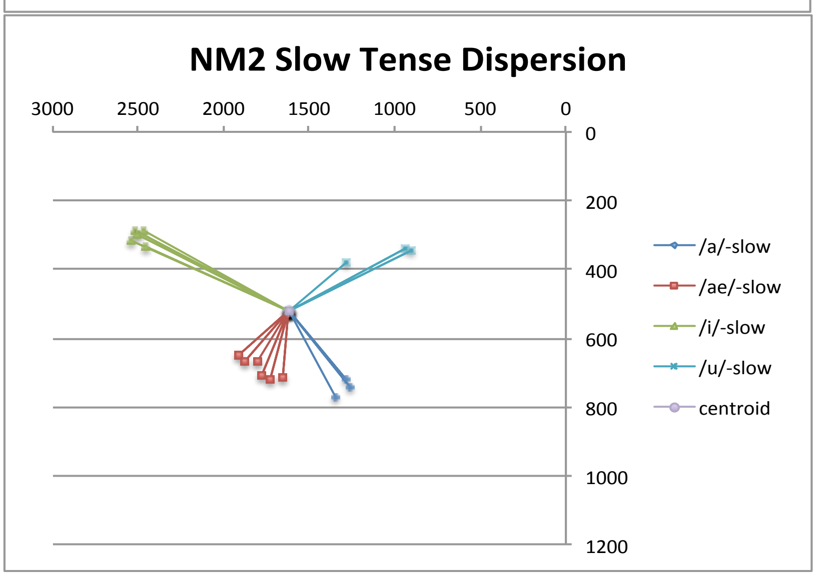




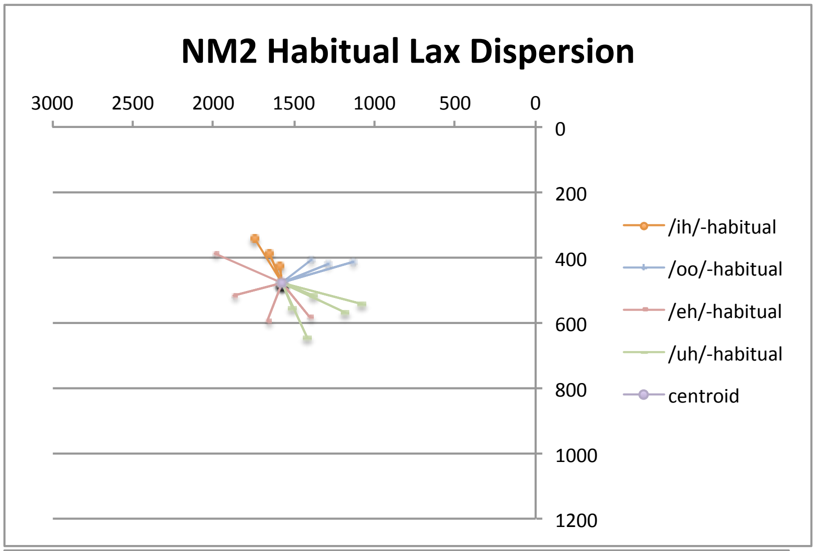
Normal Male 2 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

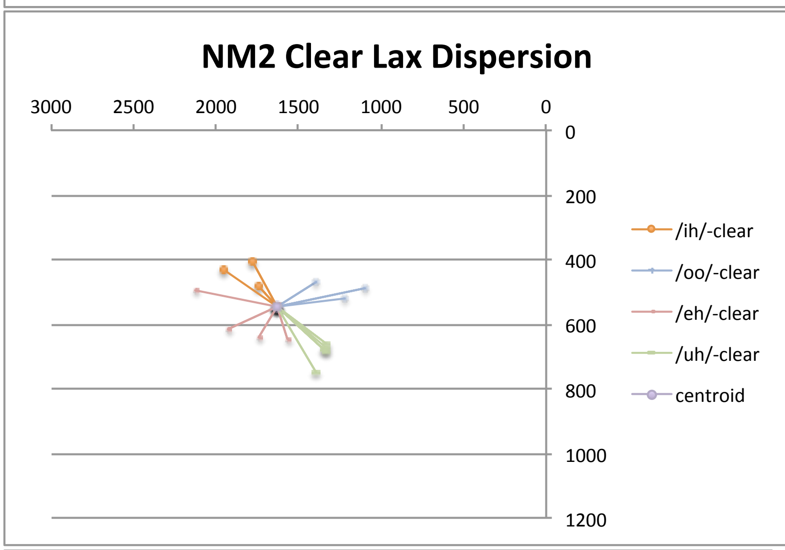


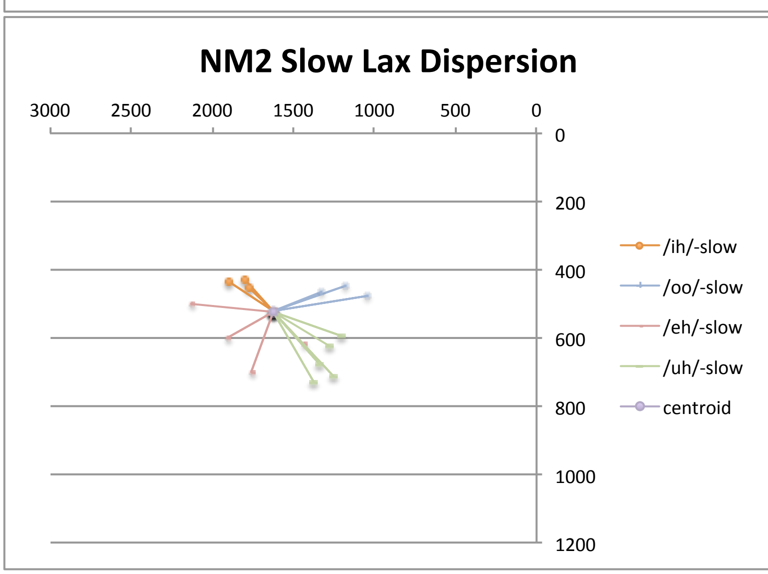




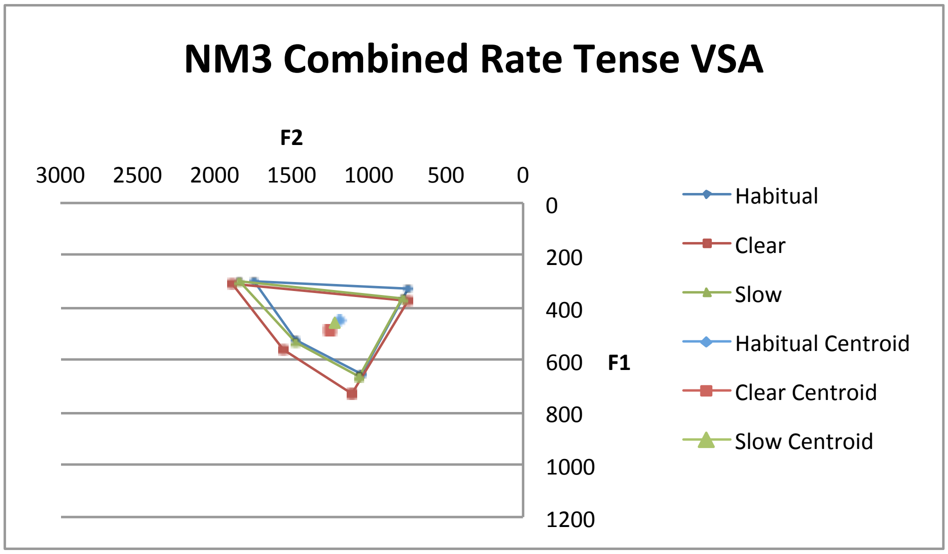
Normal Male 2 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

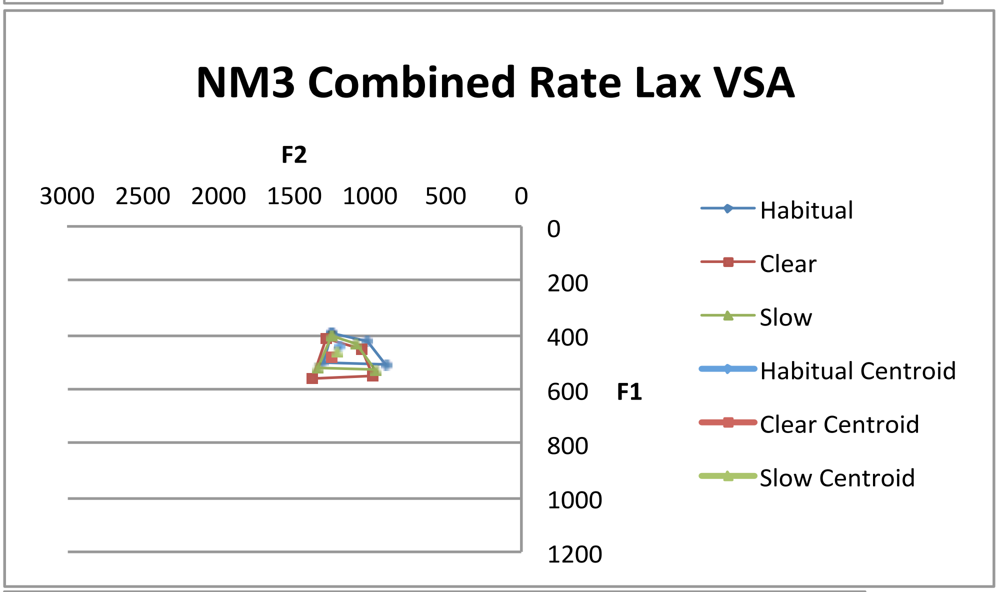


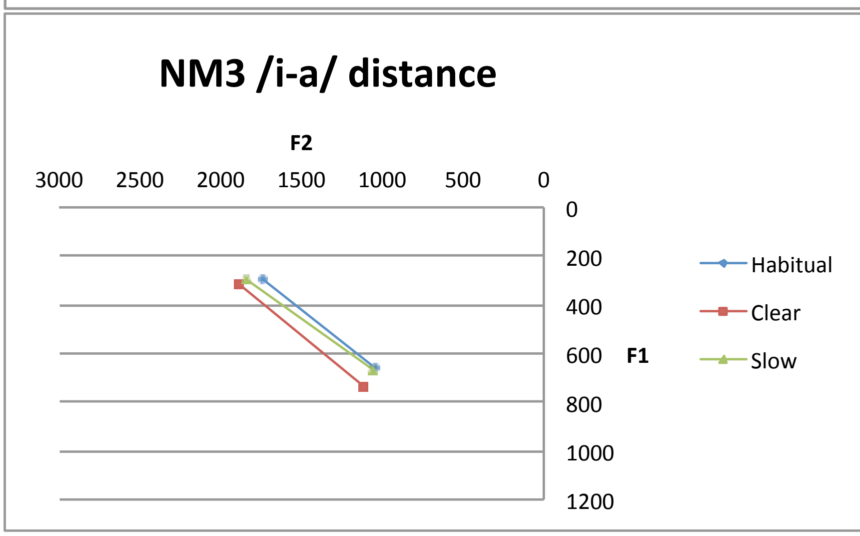




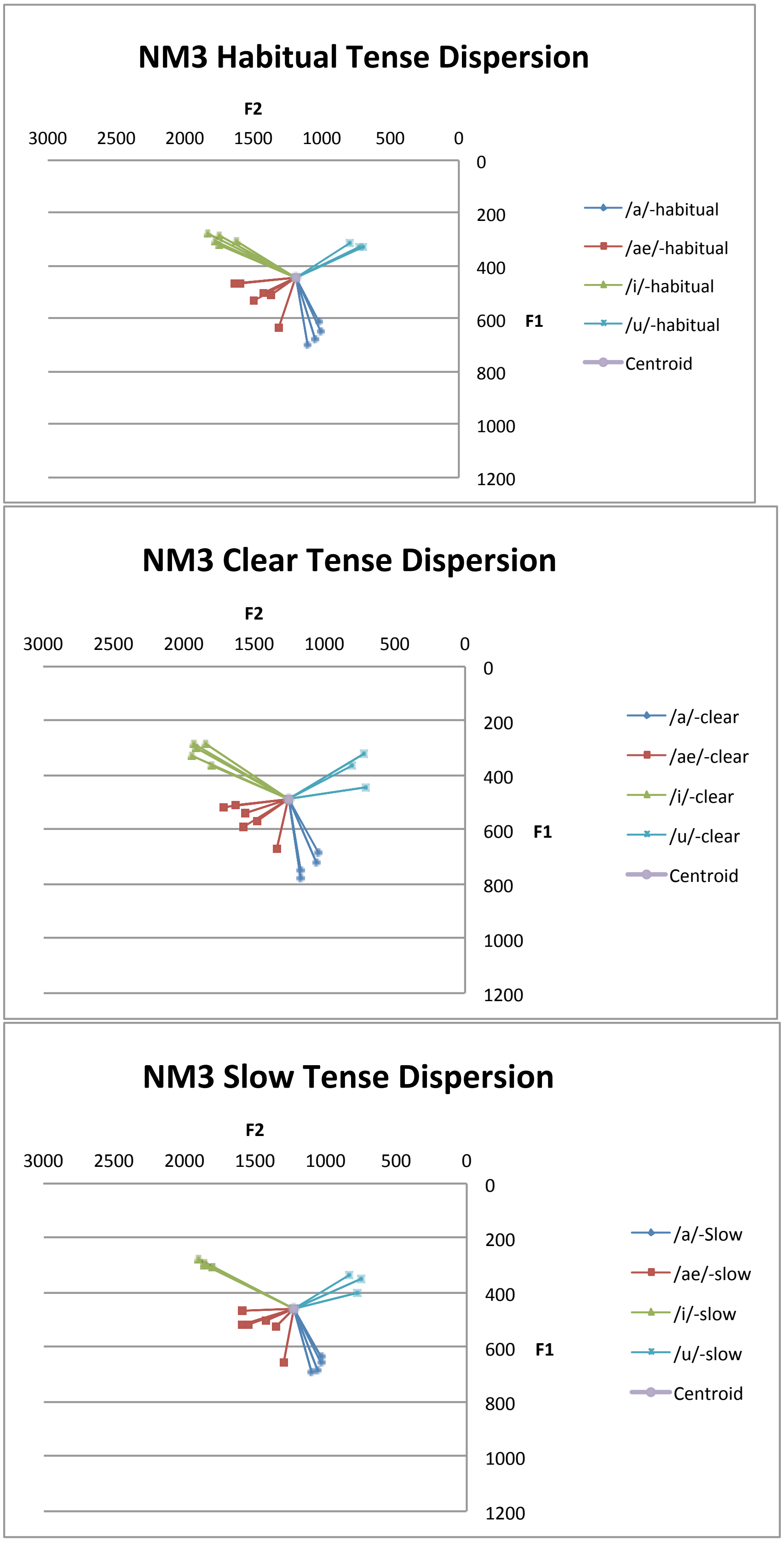
Normal Male 2 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).



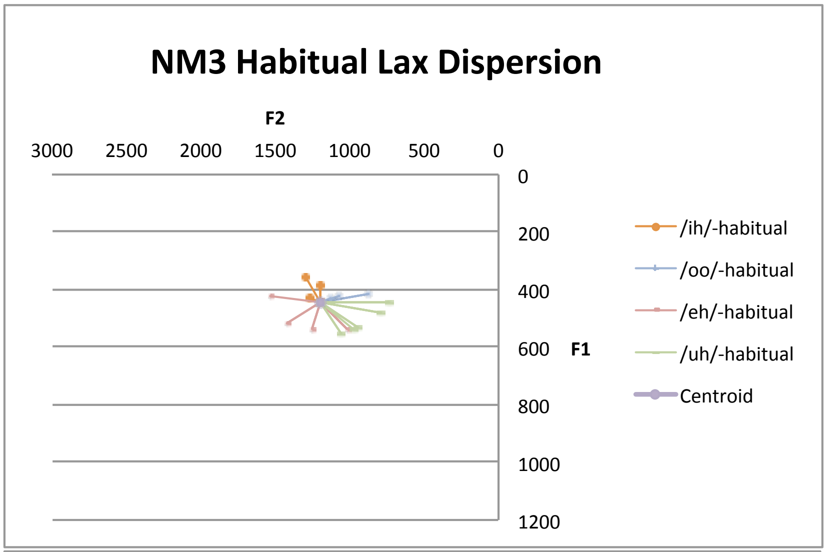


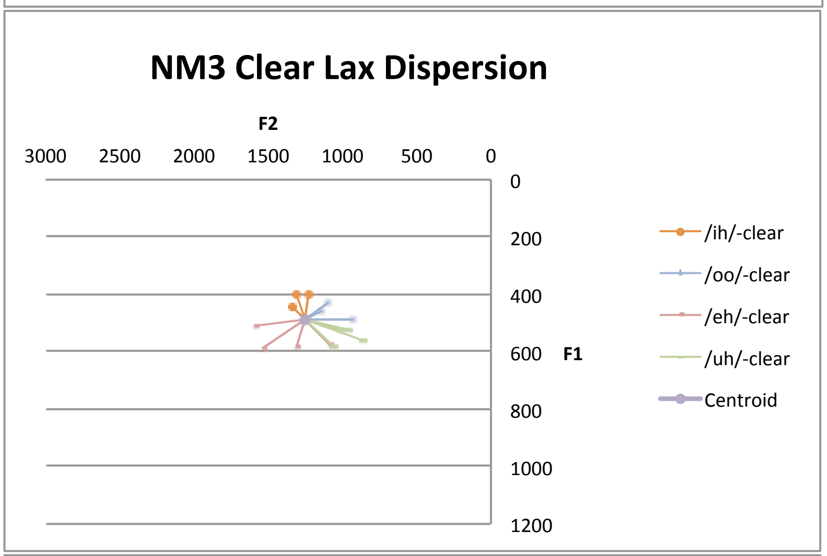


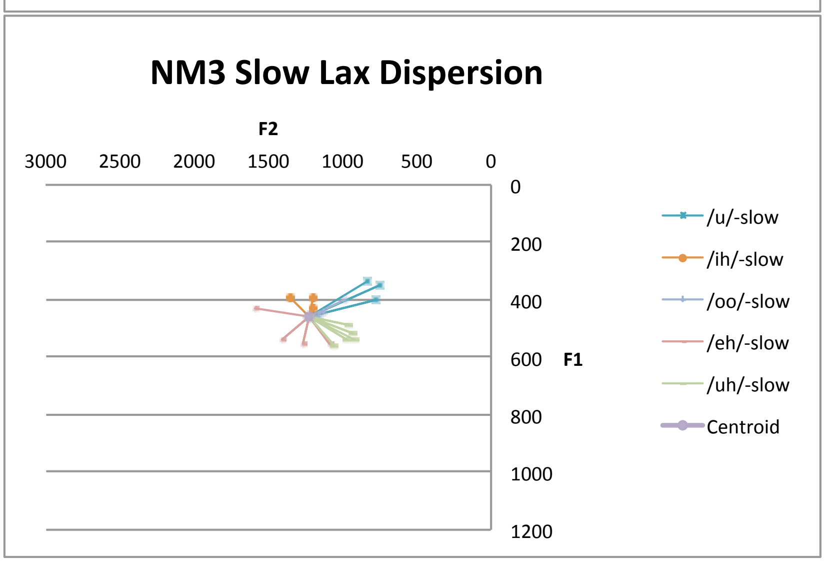
Normal Male 3 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.



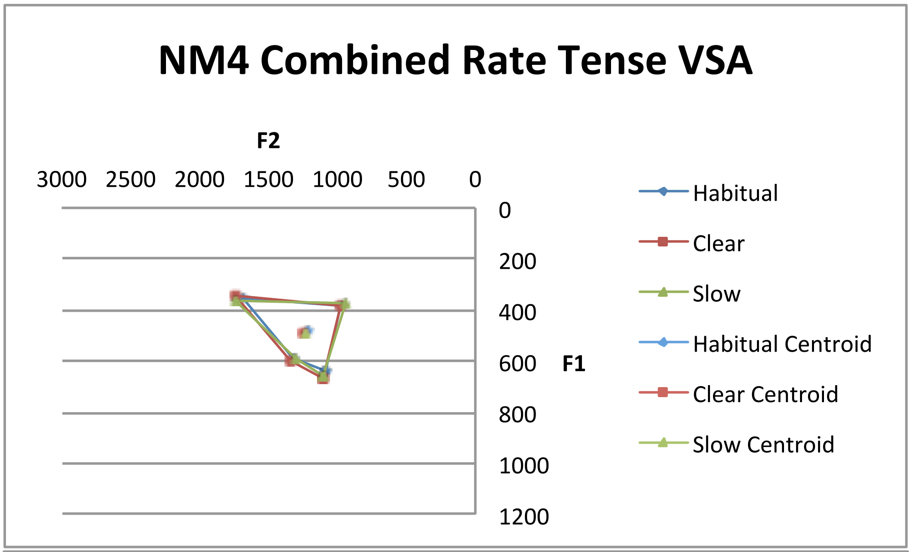
Normal Male 3 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

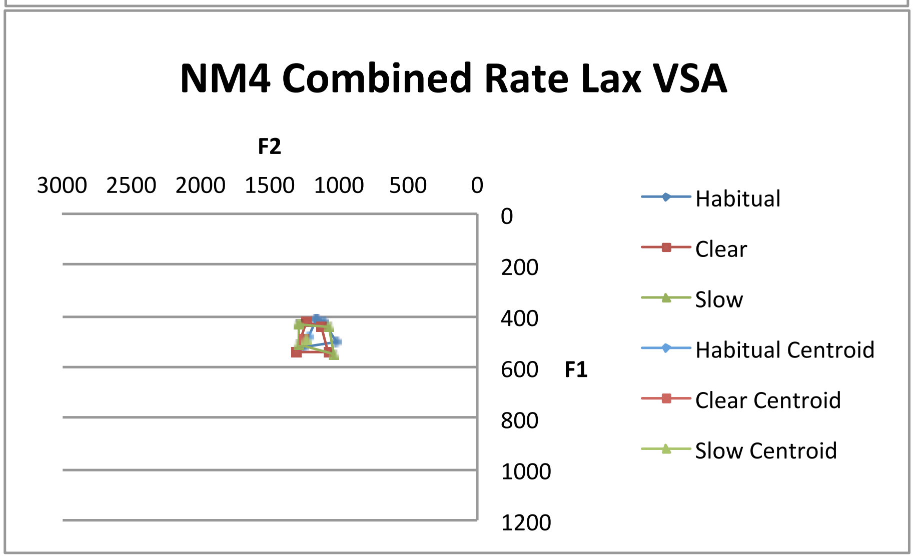


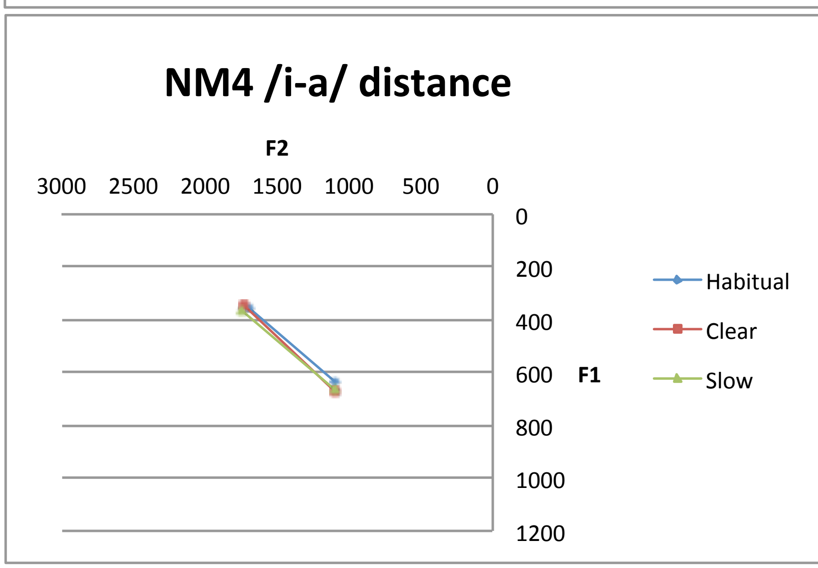




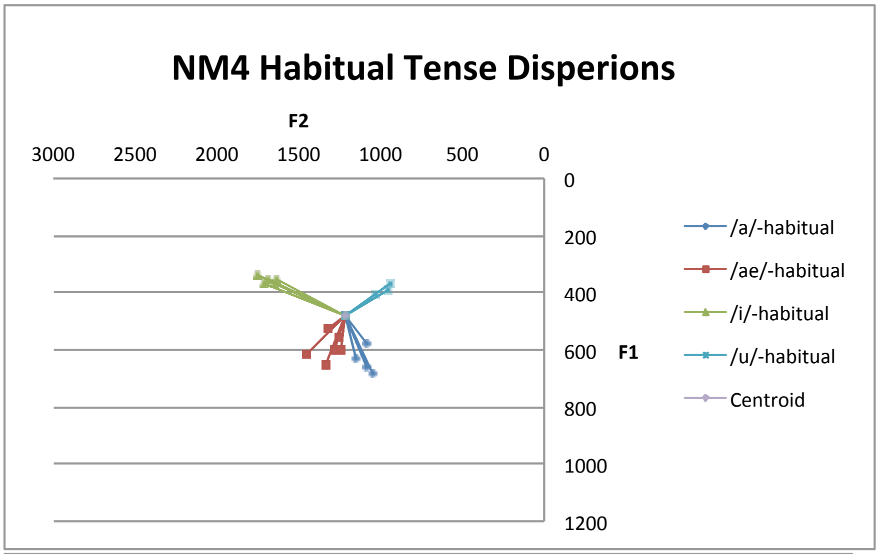
Normal Male 3 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

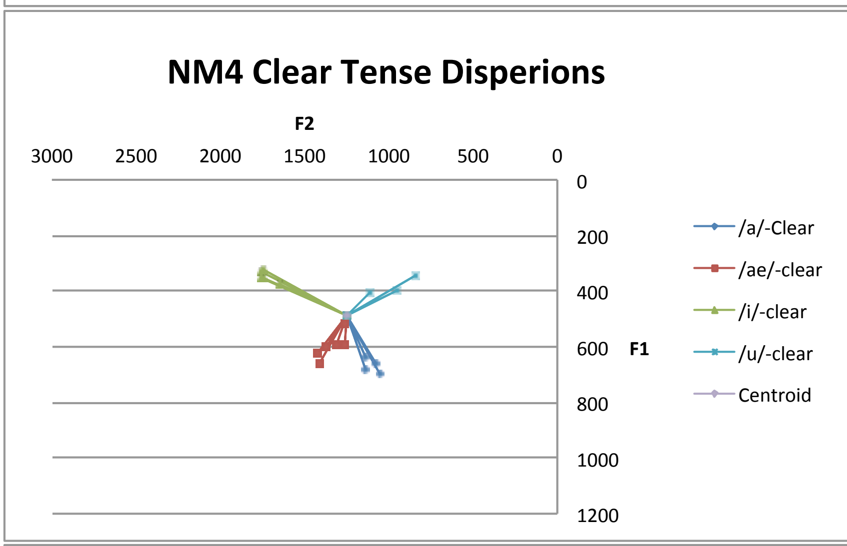


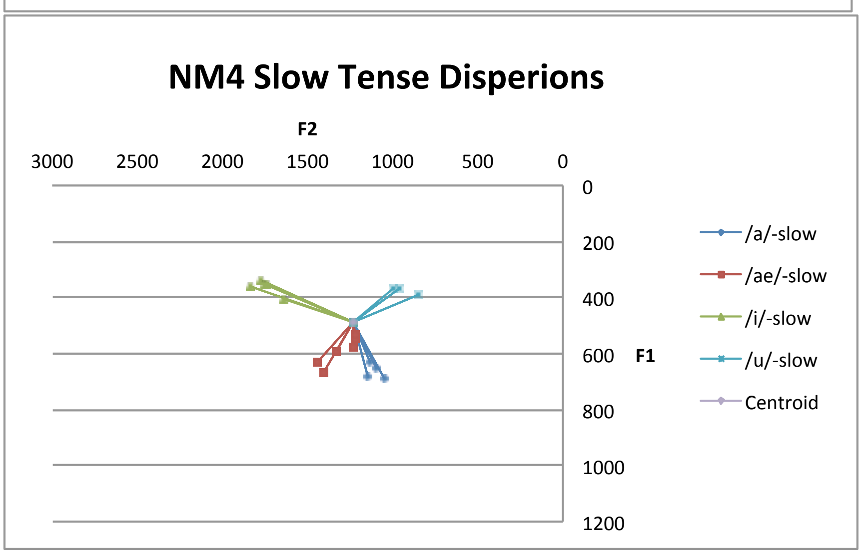




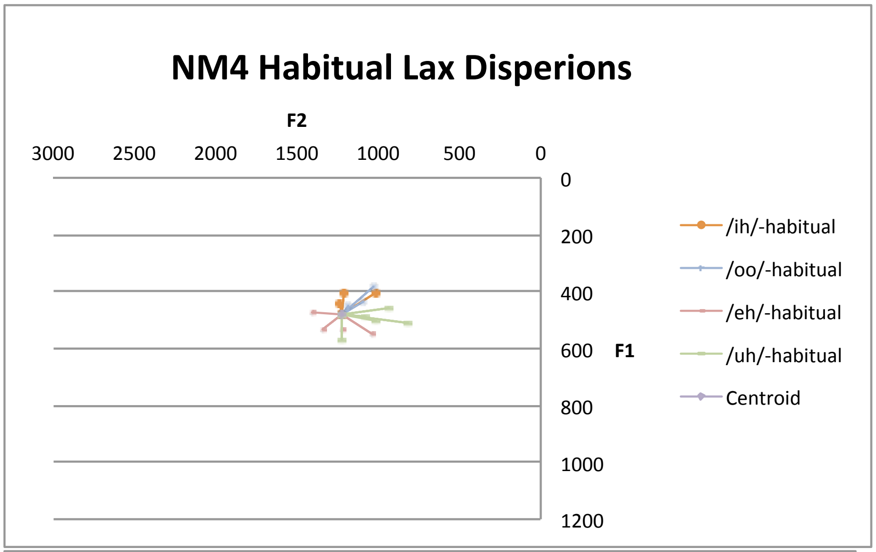
Normal Male 4 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

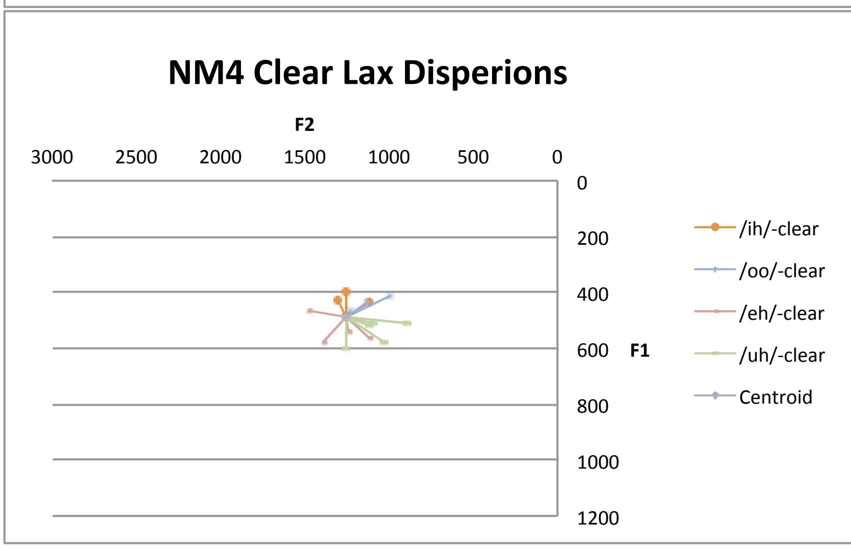


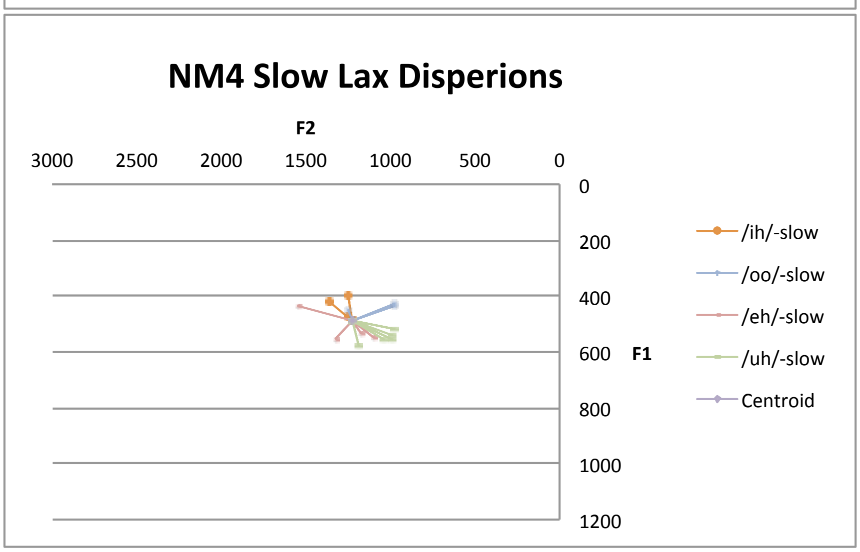




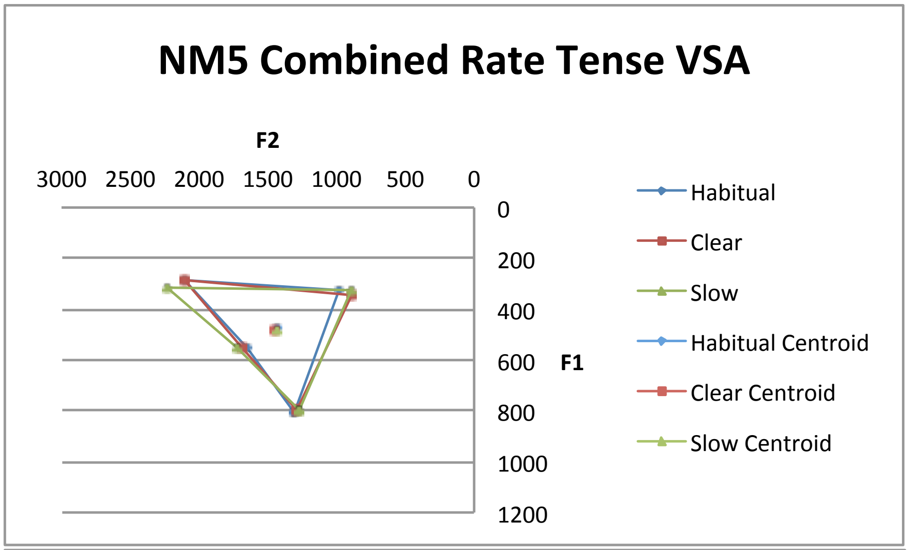
Normal Male 4 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

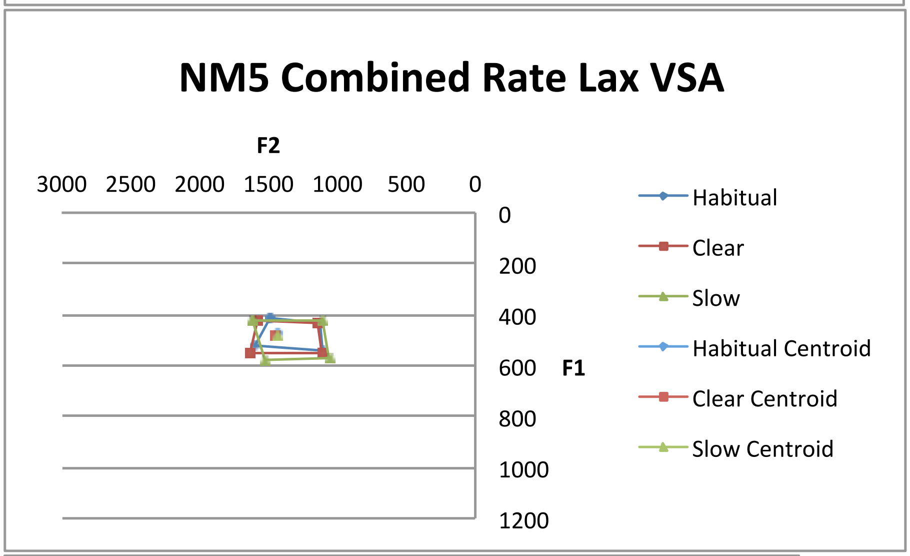


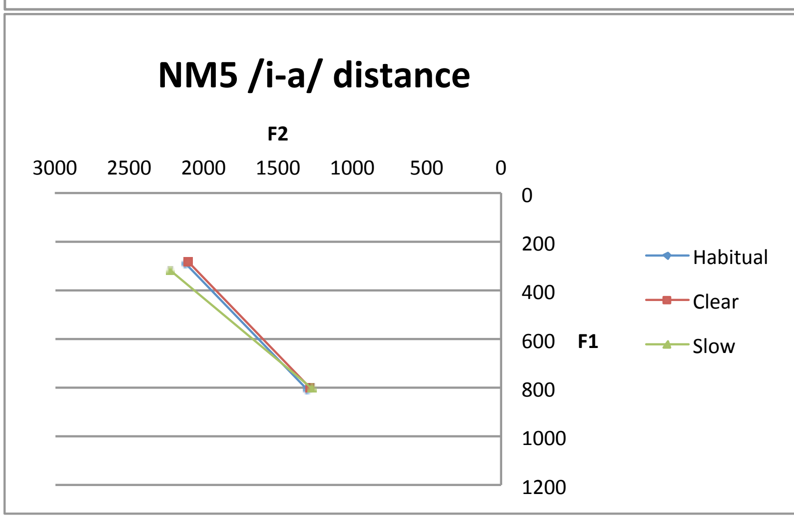




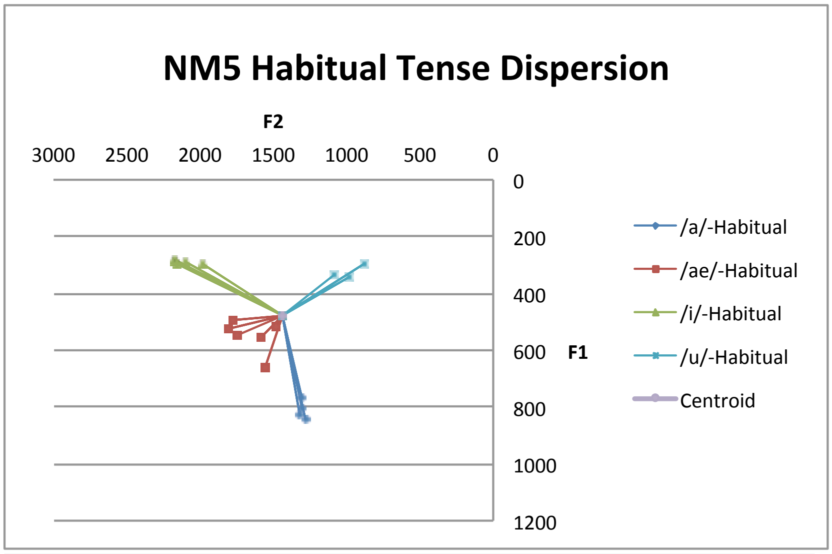
Normal Male 4 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

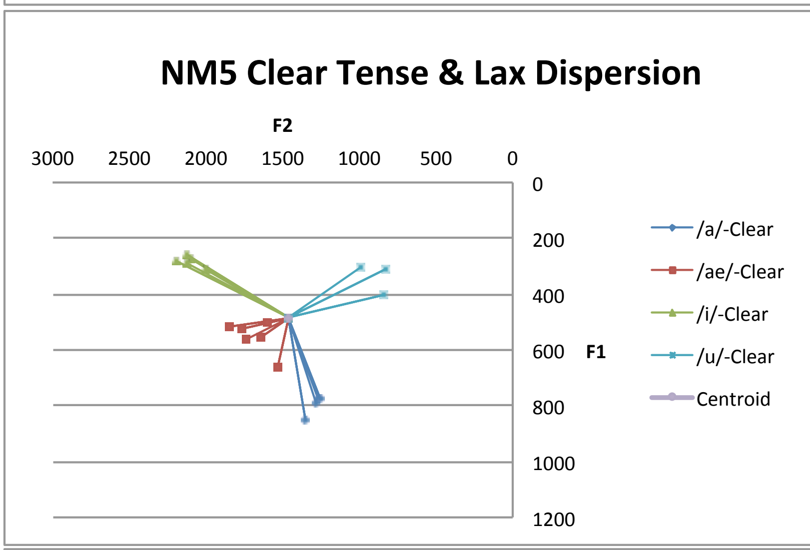


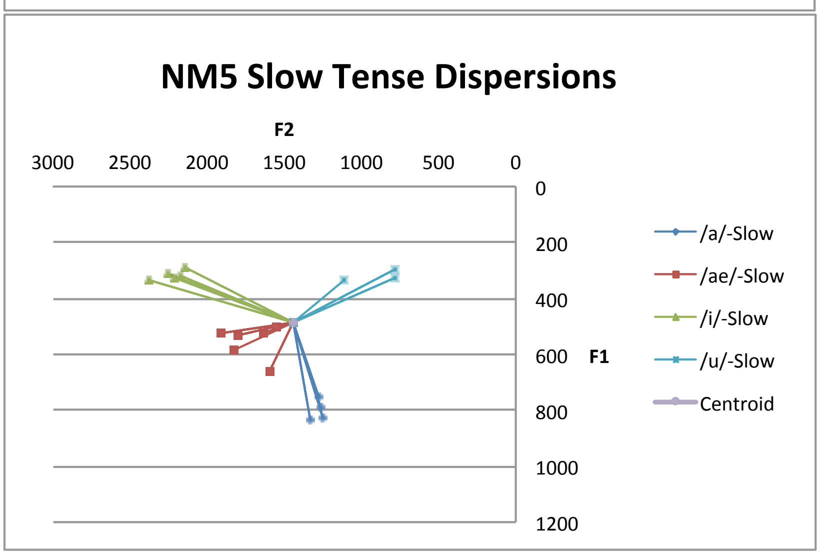




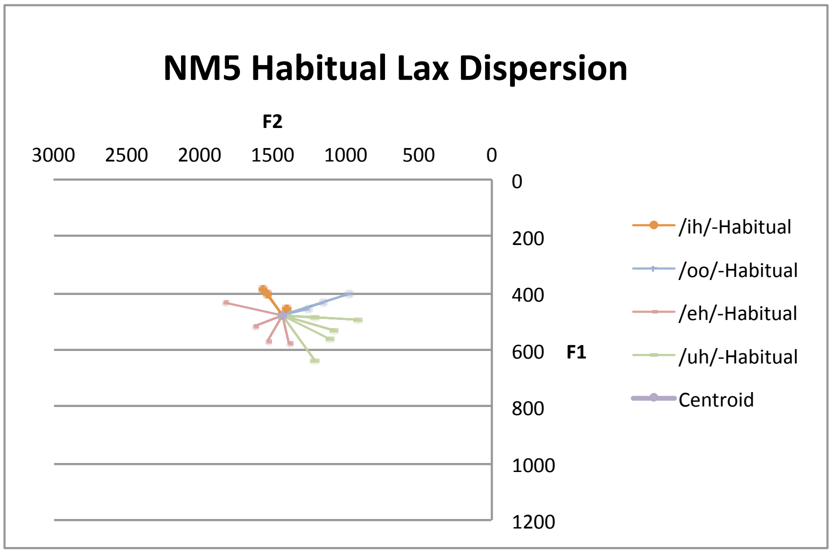
Normal Male 5 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

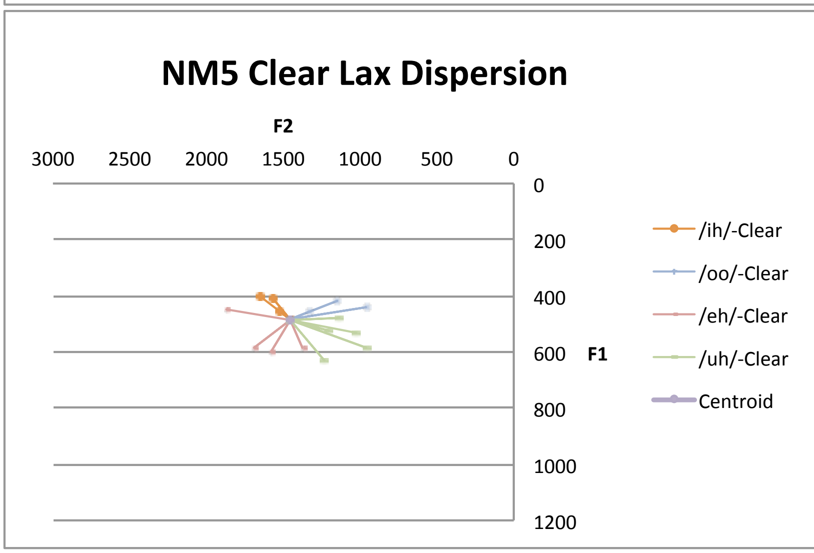


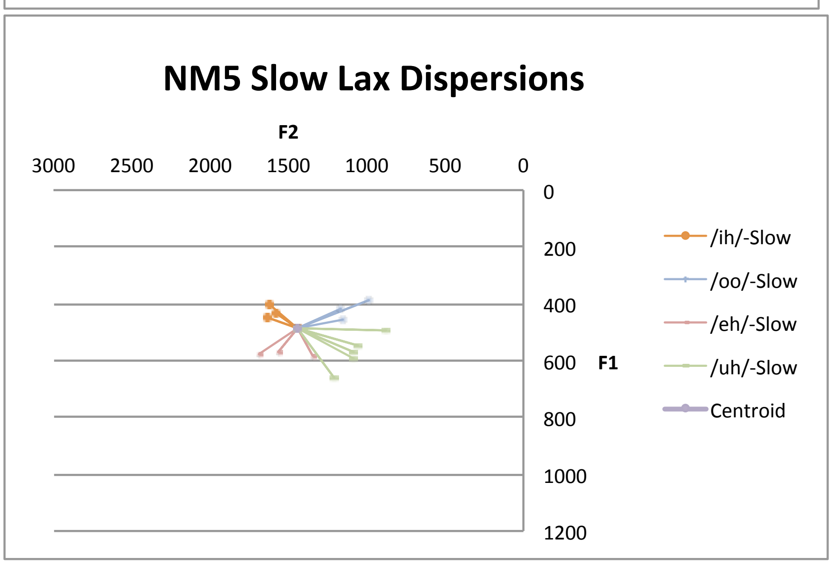




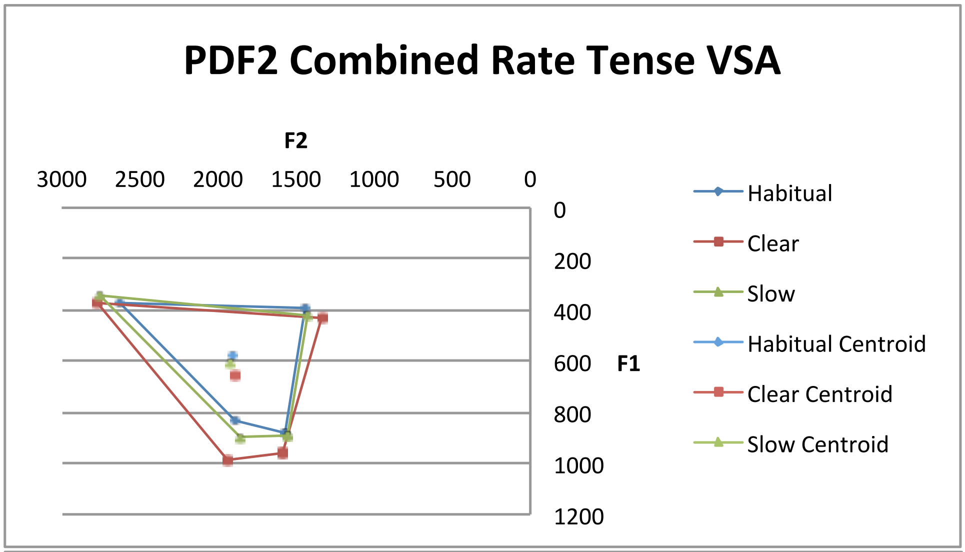
Normal Male 5 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

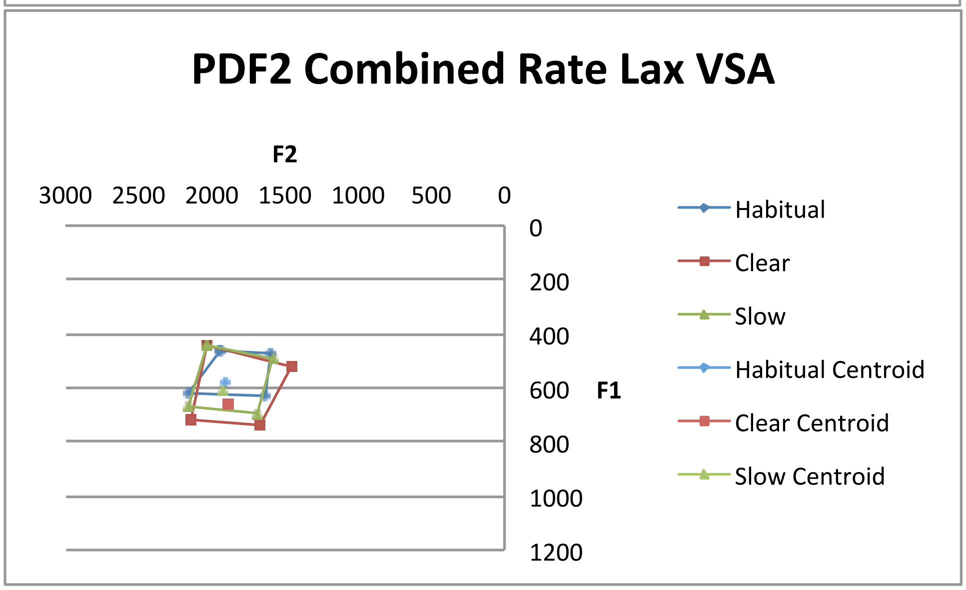


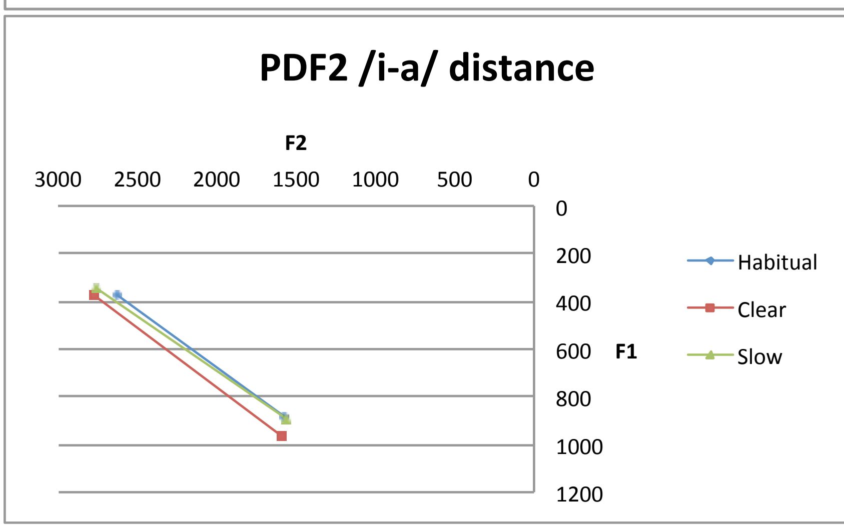




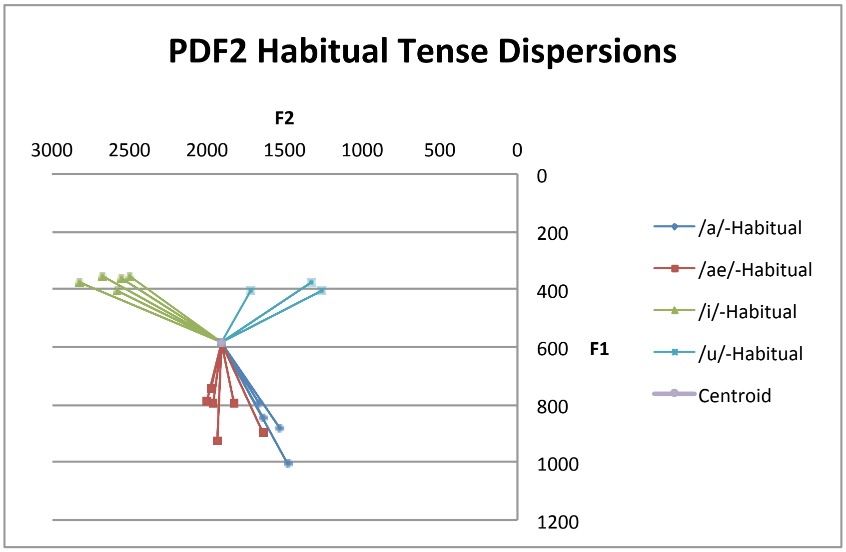
Normal Male 5 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

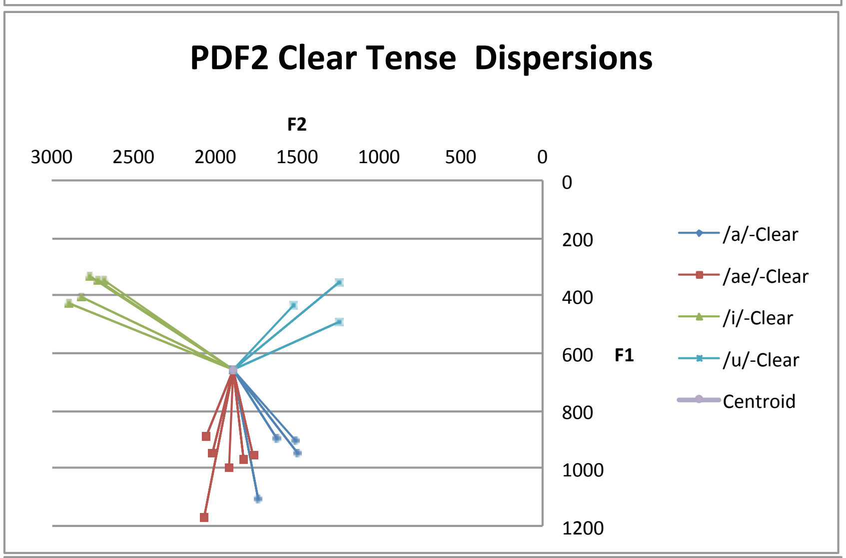


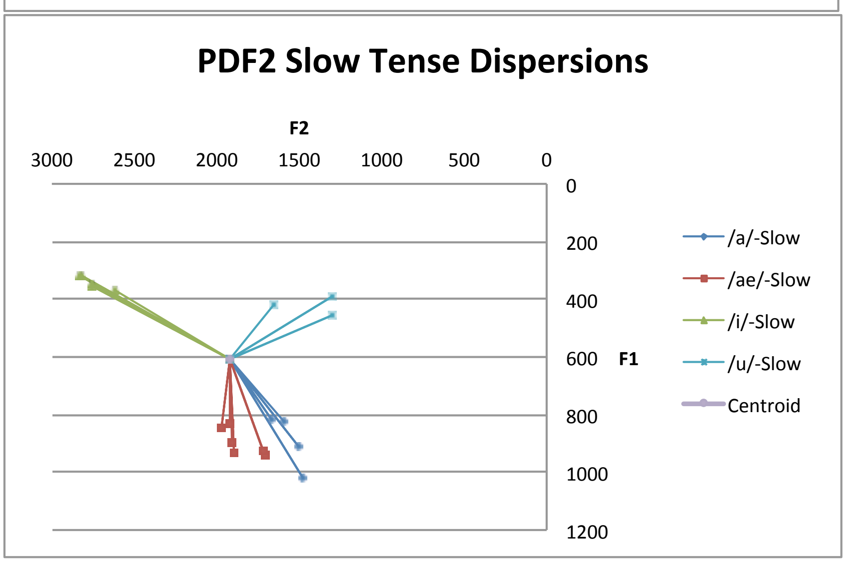




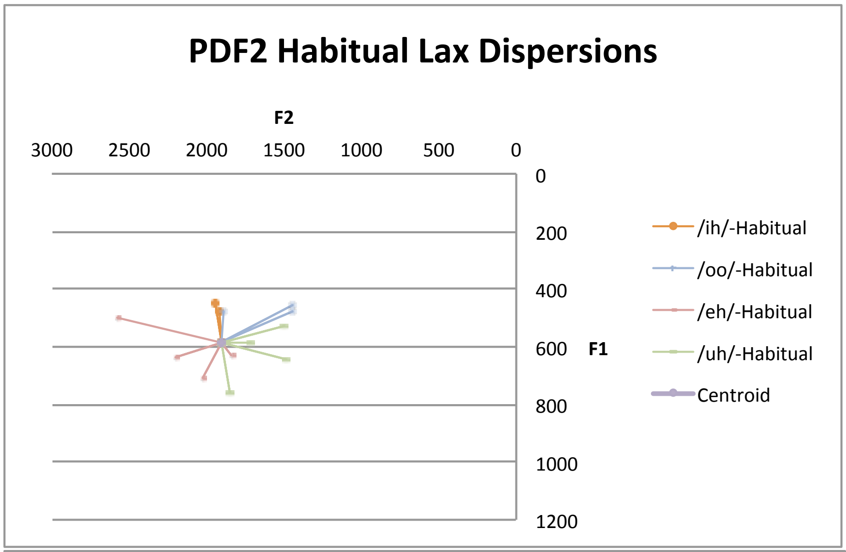
Parkinson's Female 2 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

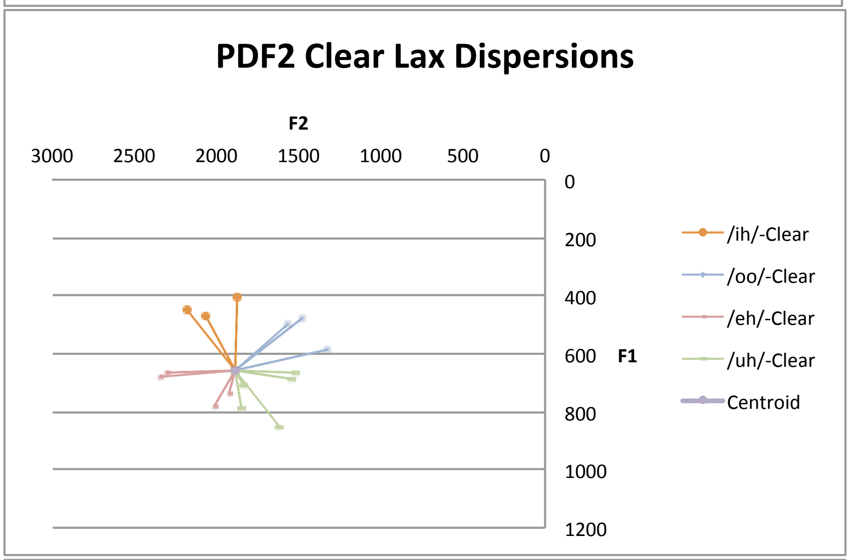


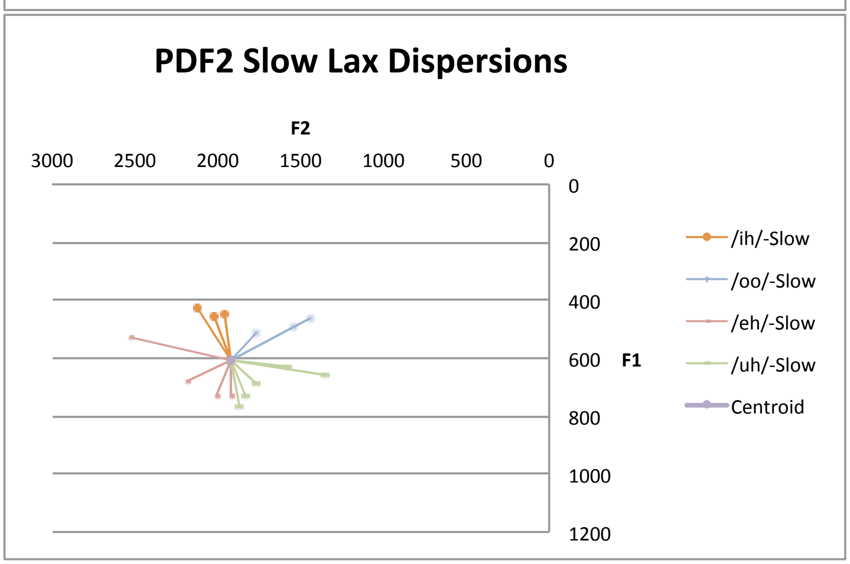




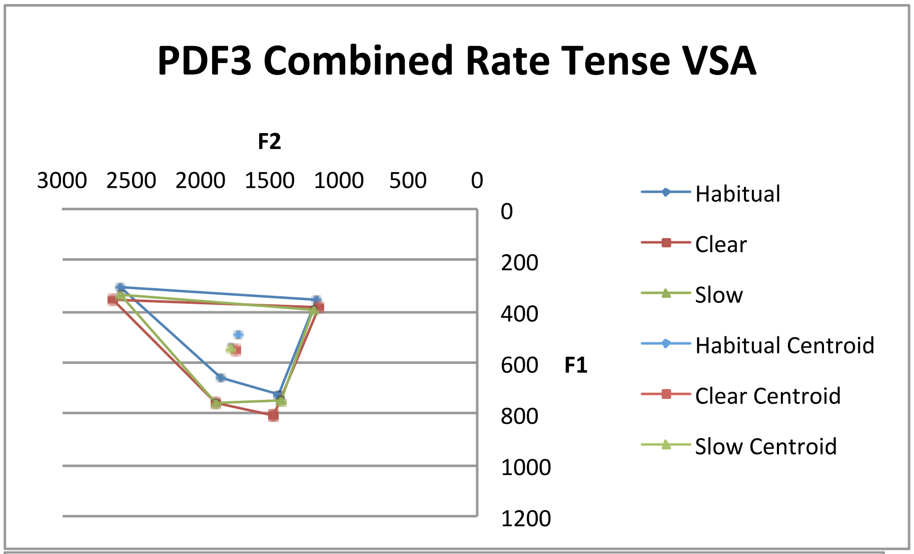
Parkinson's Female 2 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

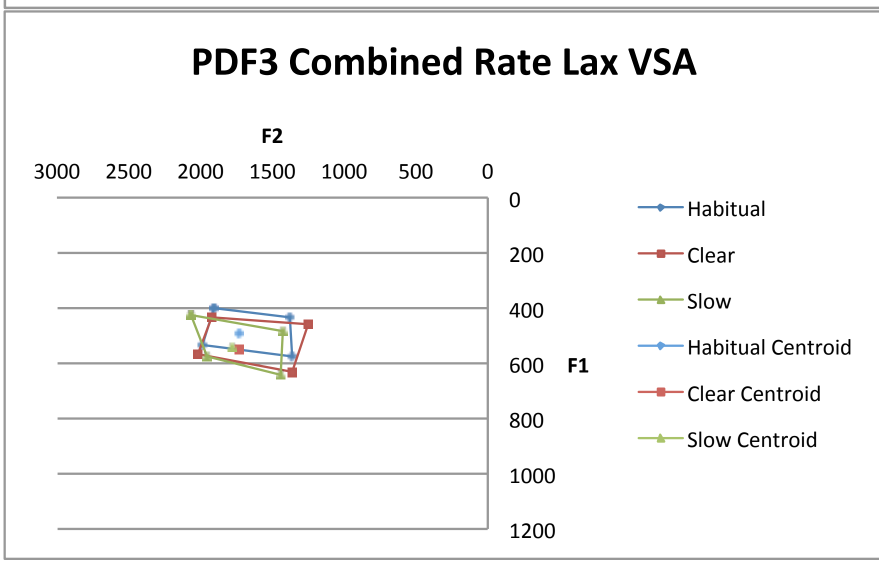


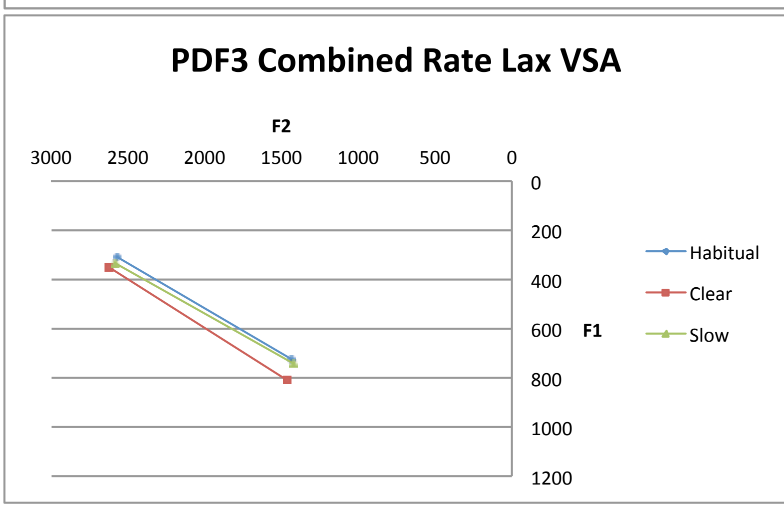




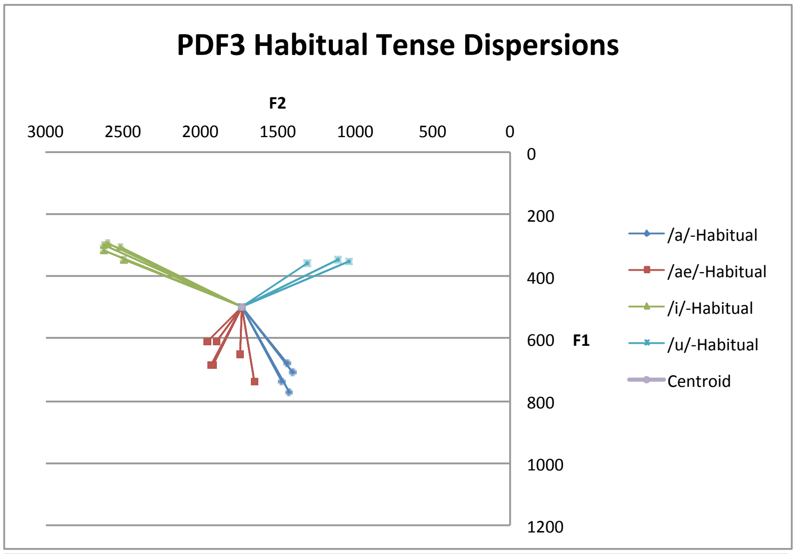
Parkinson's Female 2 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

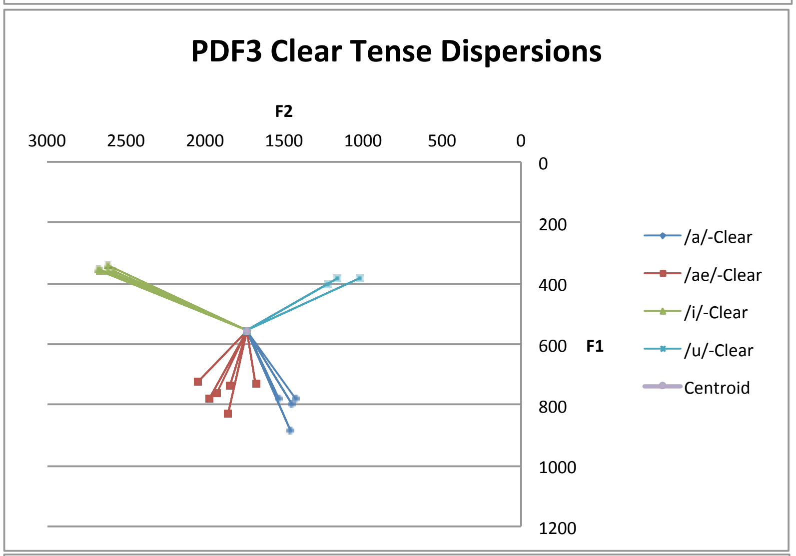


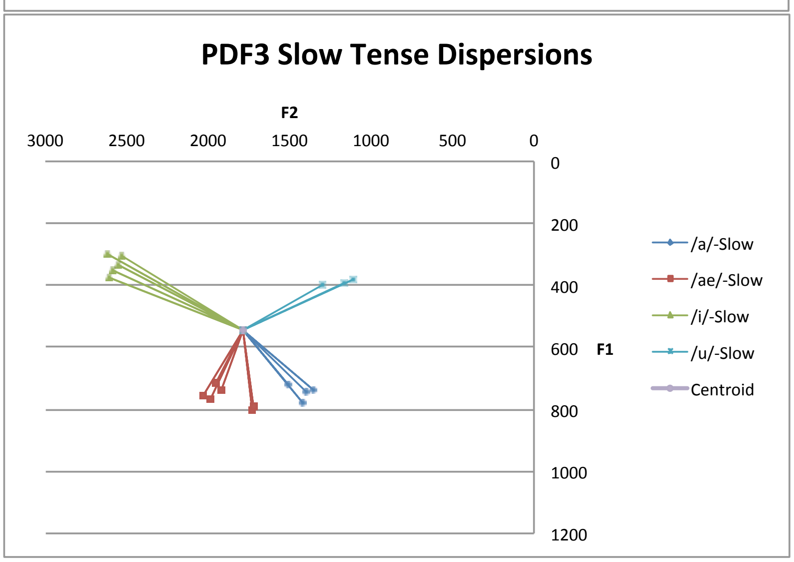




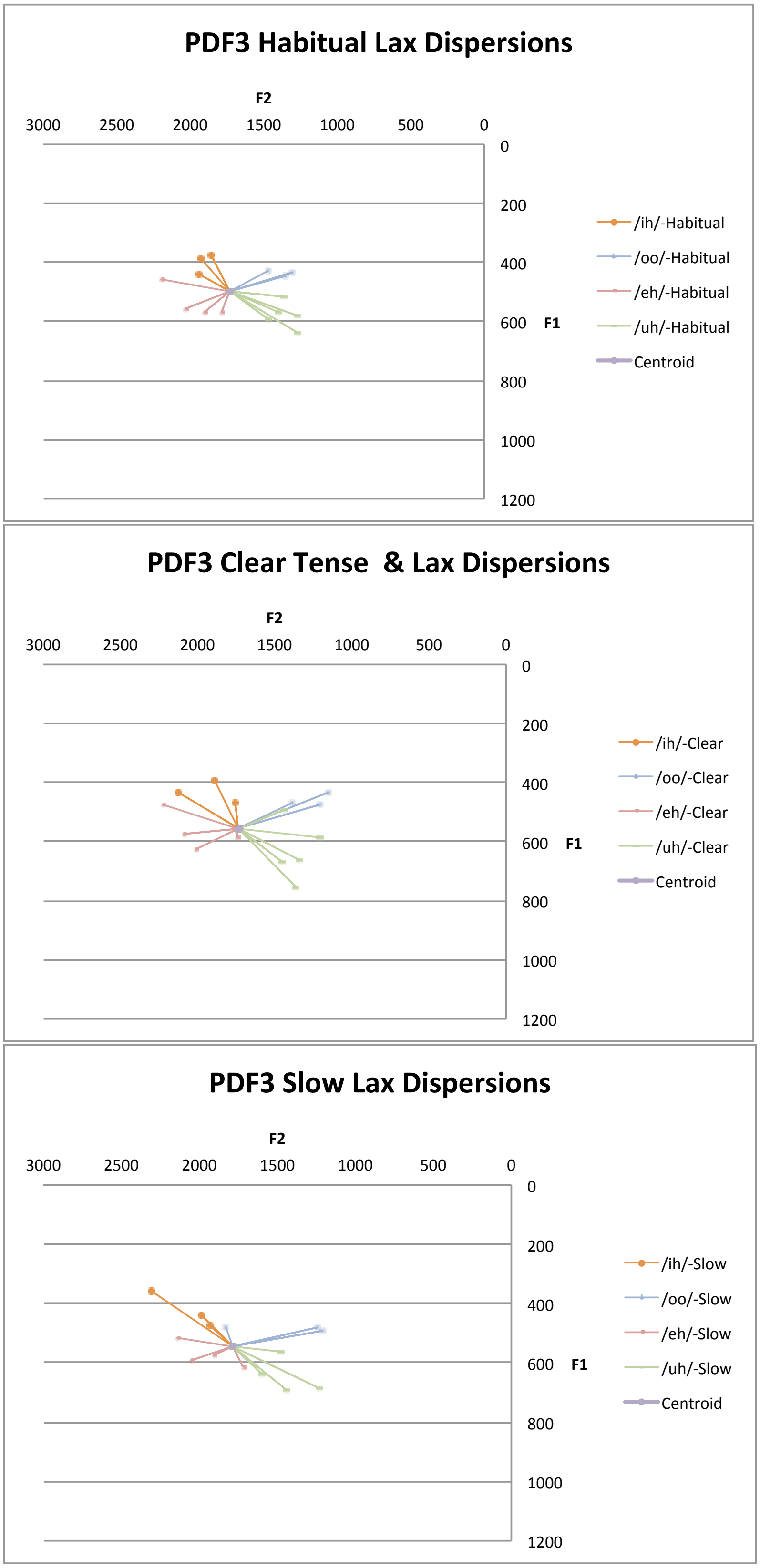
Parkinson's Female 3 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.



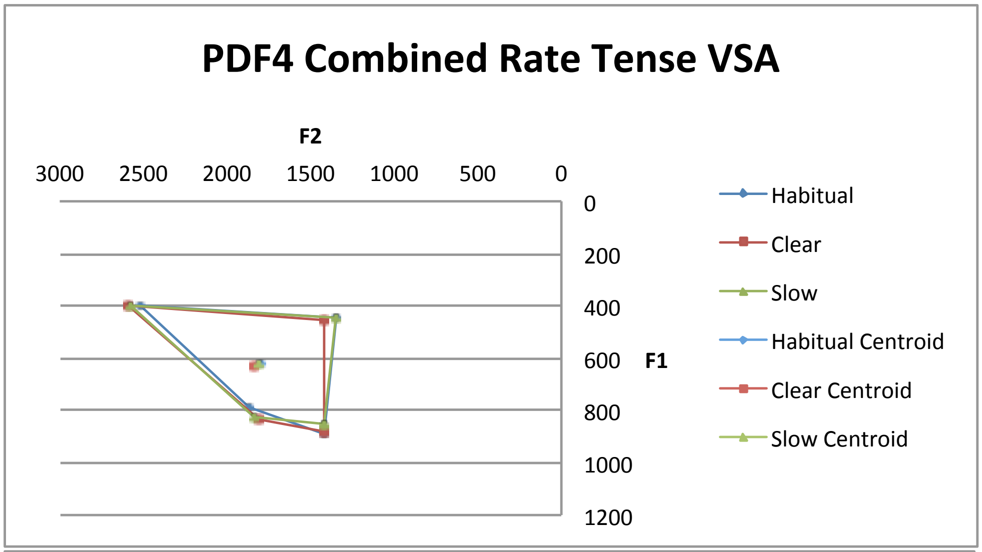


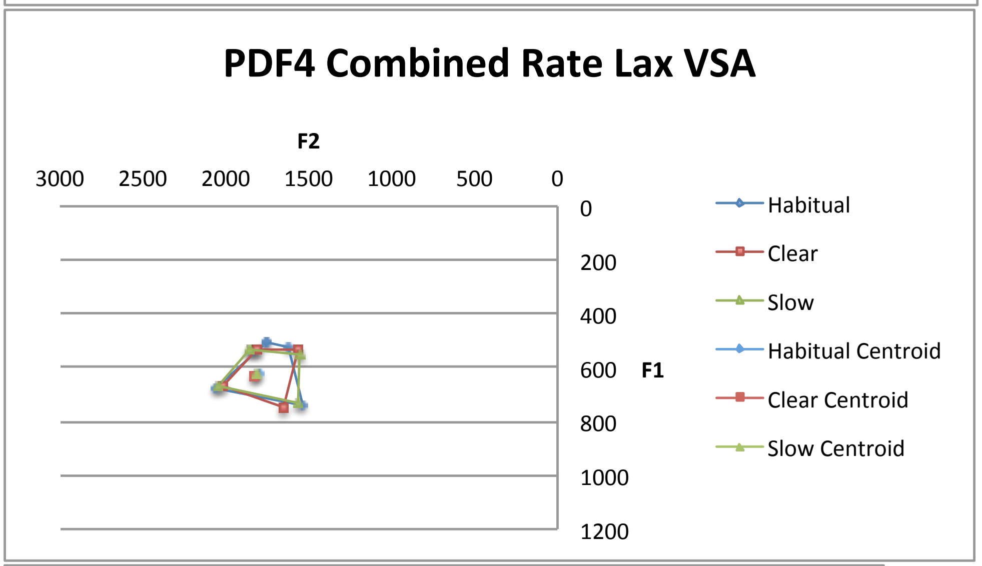


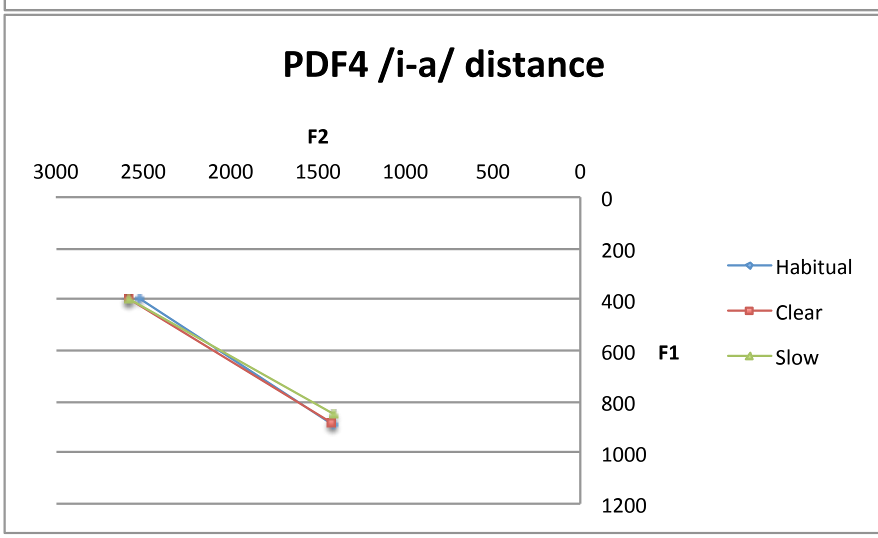
Parkinson's Female 3 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).



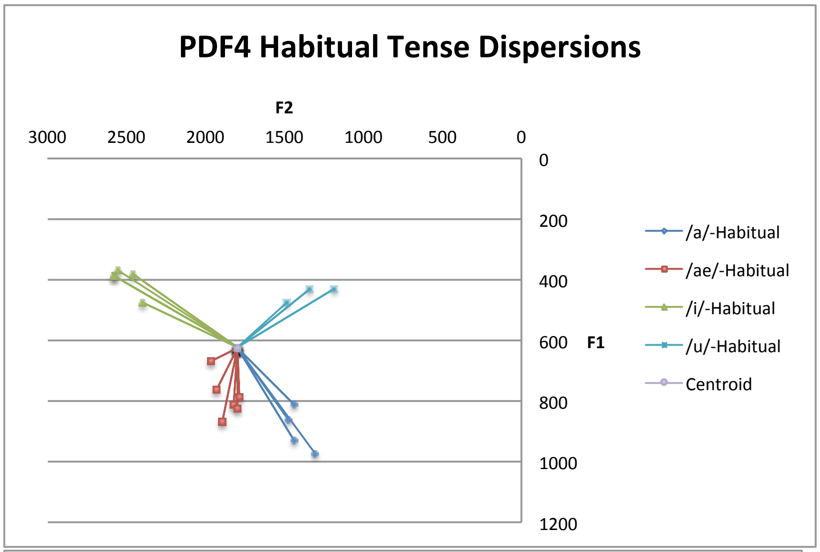
Parkinson's Female 3 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

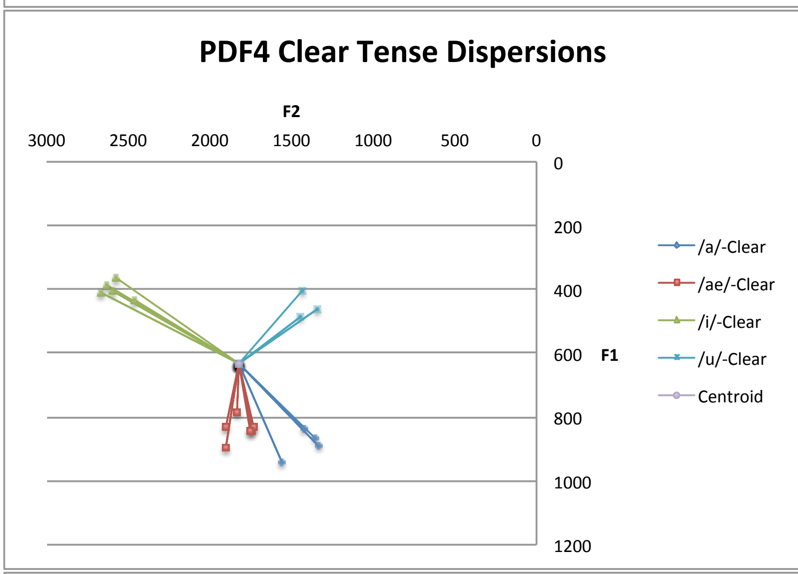


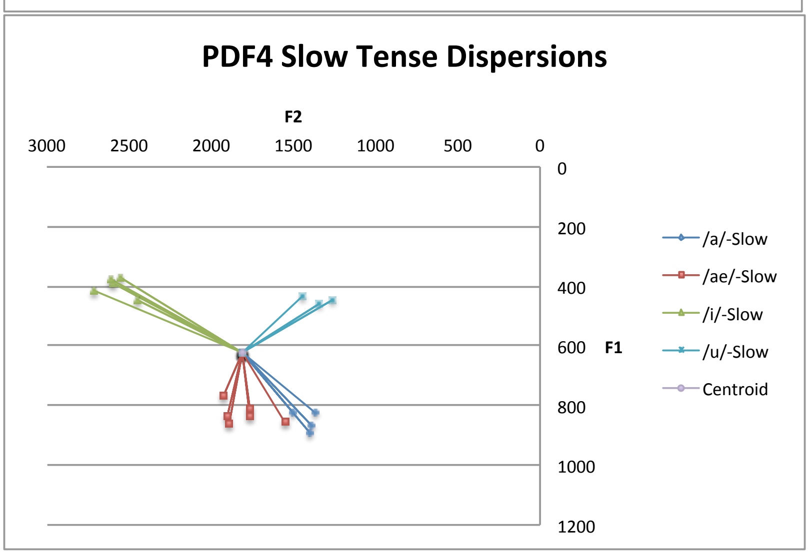




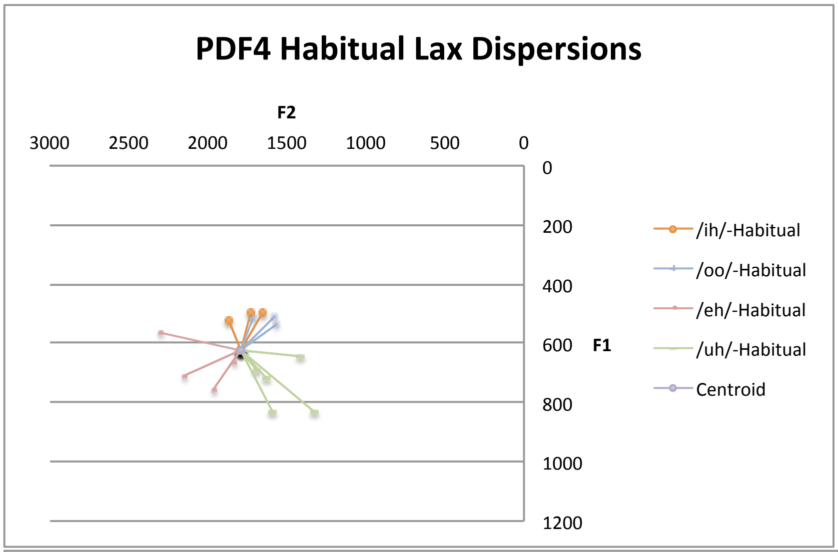
Parkinson's Female 4 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

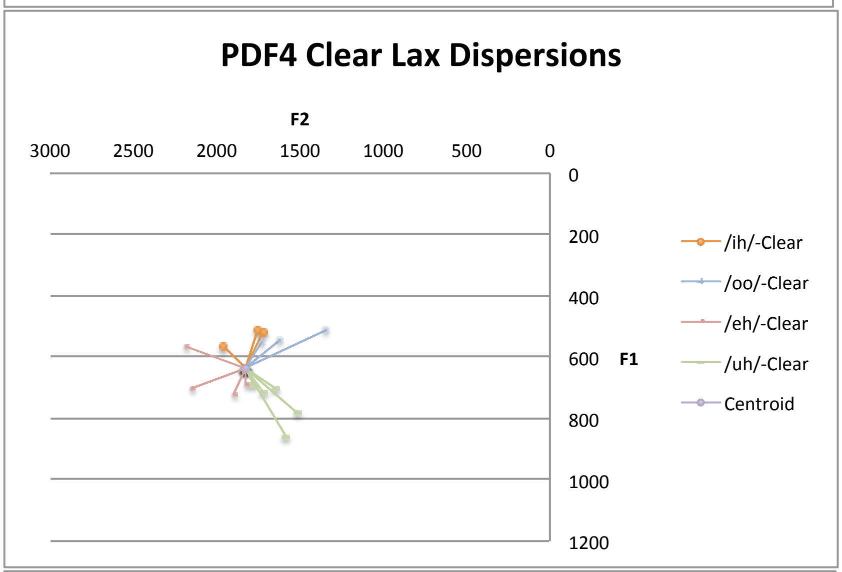


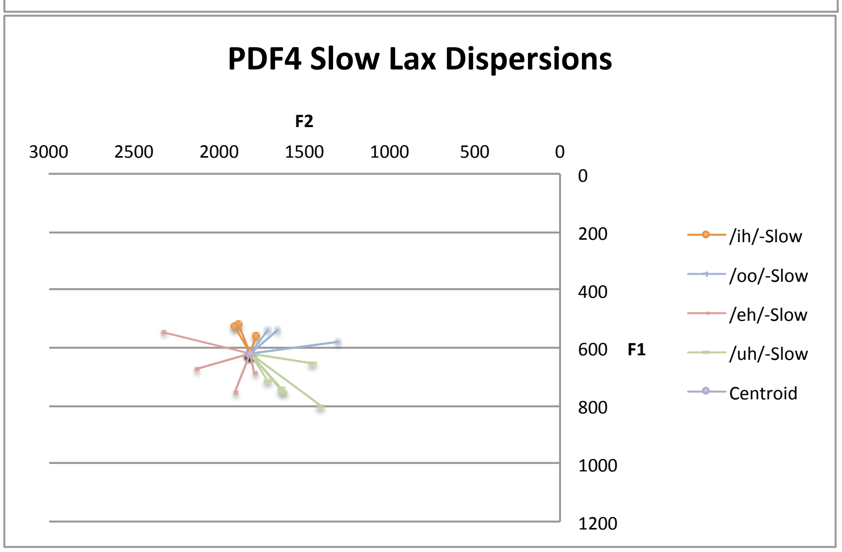




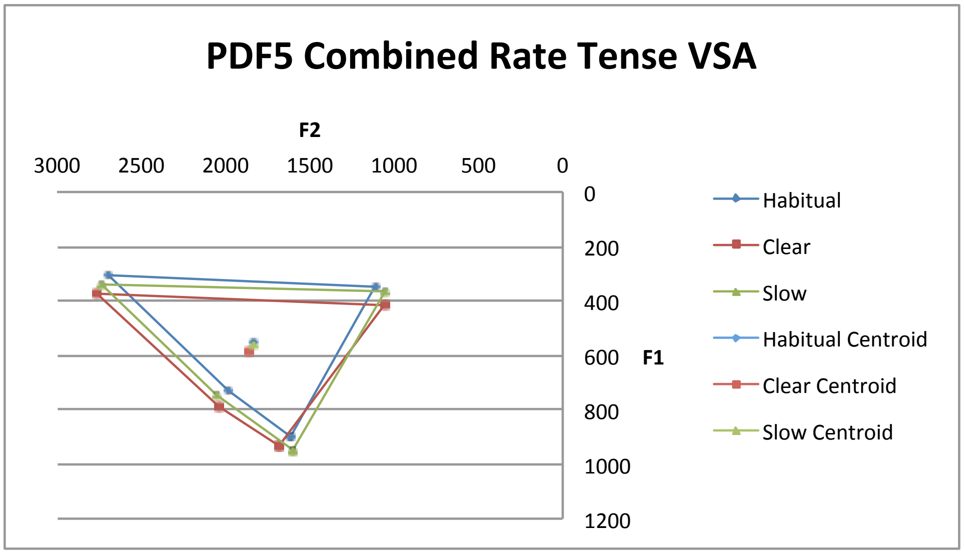
Parkinson's Female 4 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

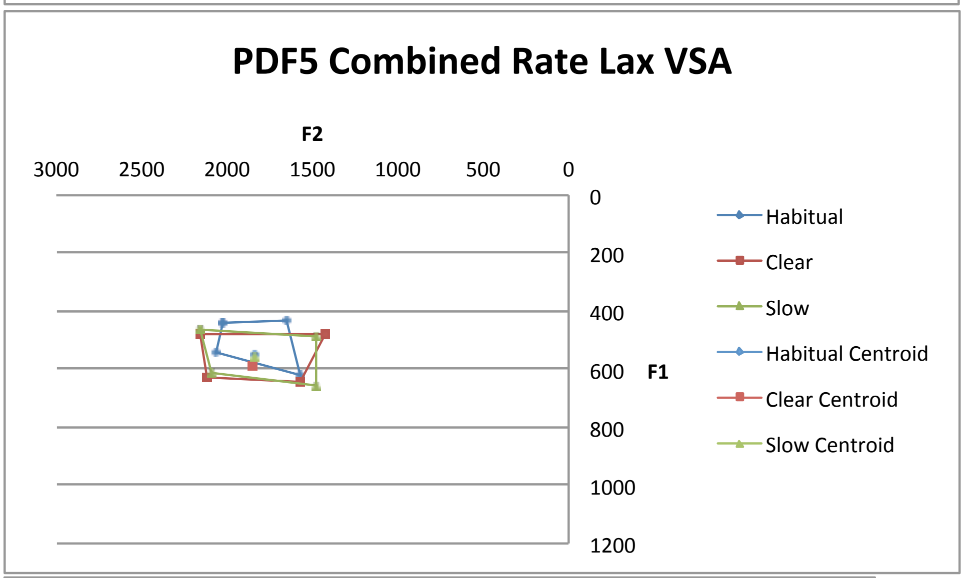


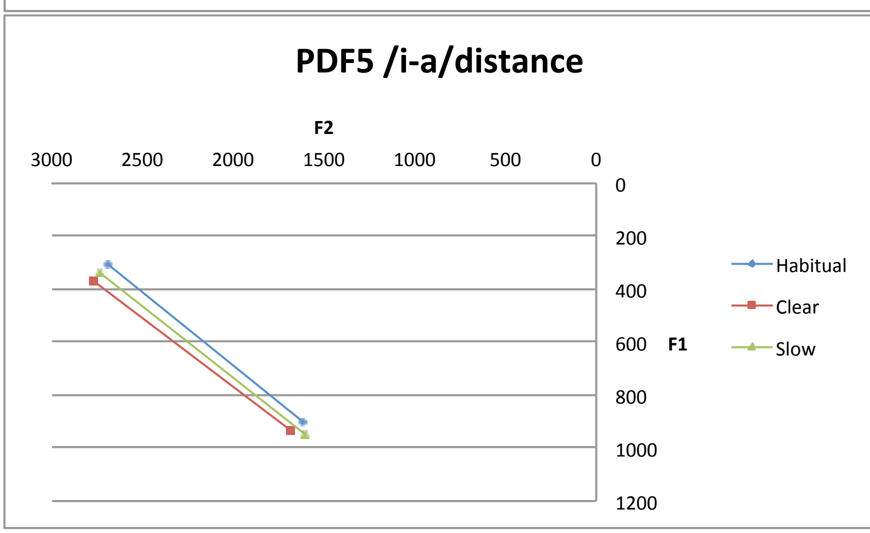




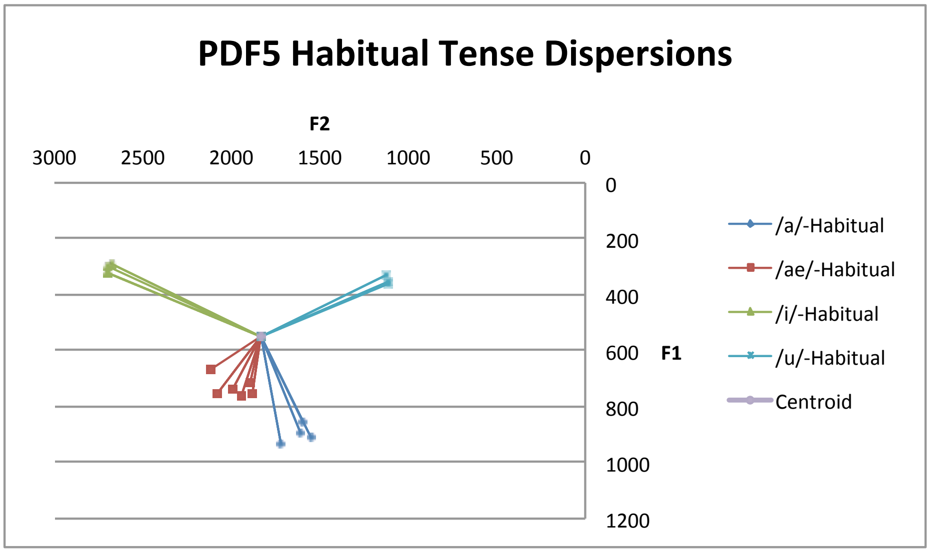
Parkinson's Female 4 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

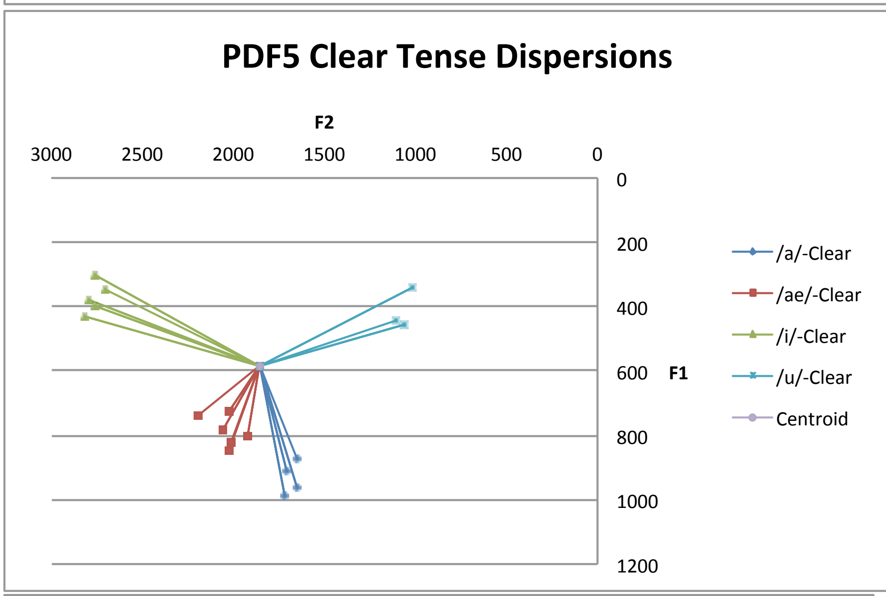


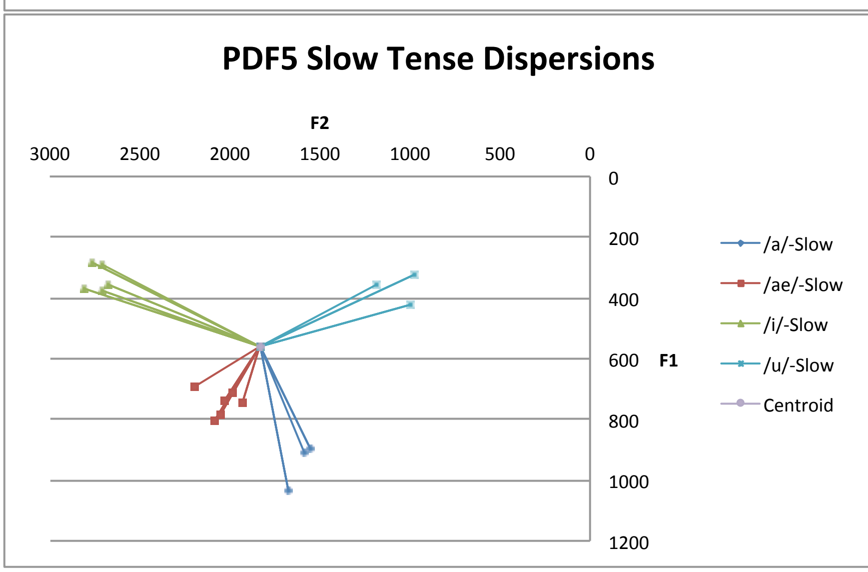




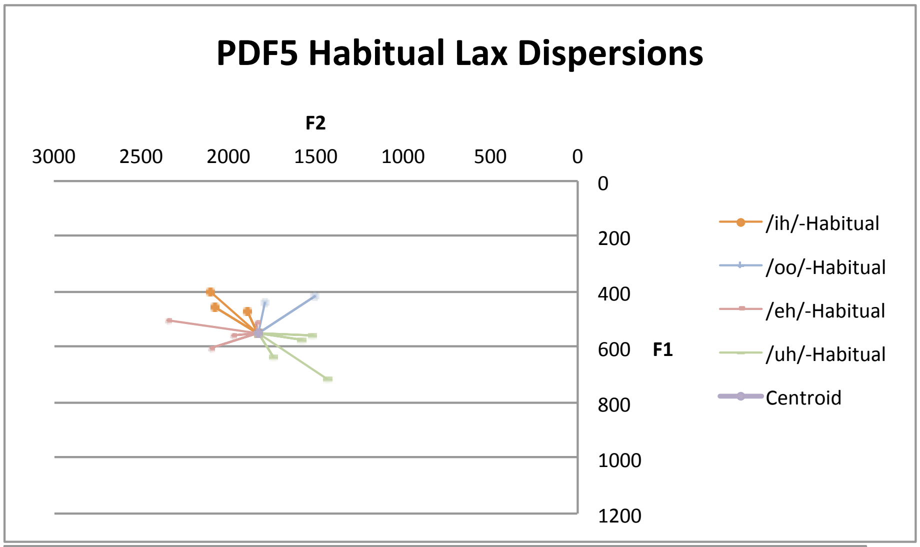
Parkinson's Female 5 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

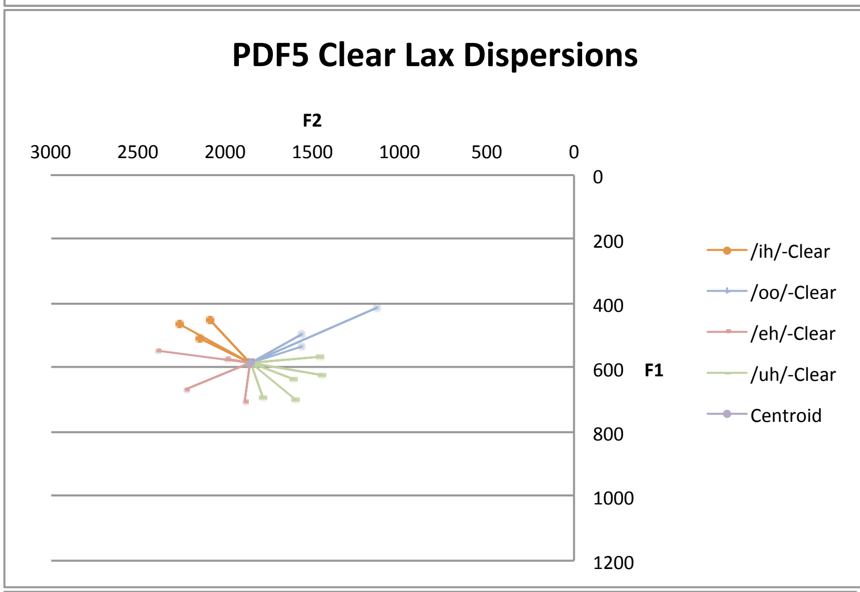


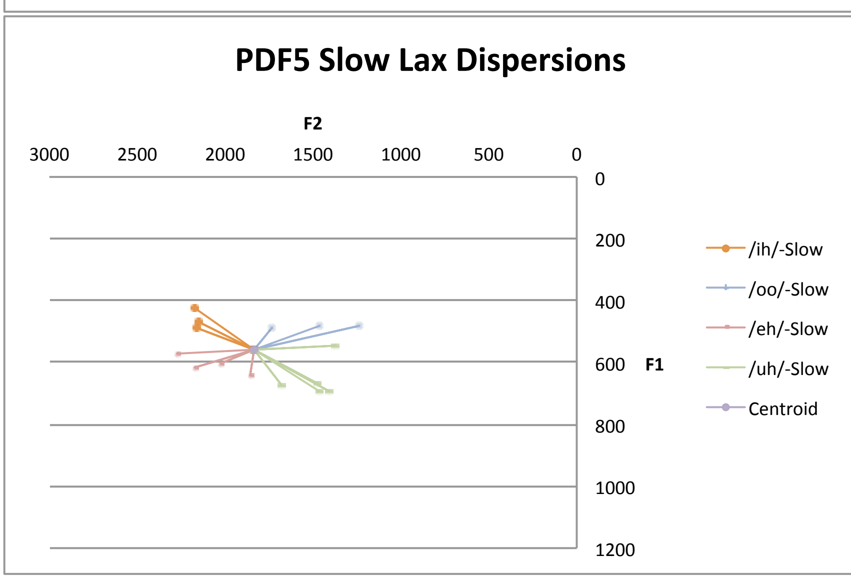




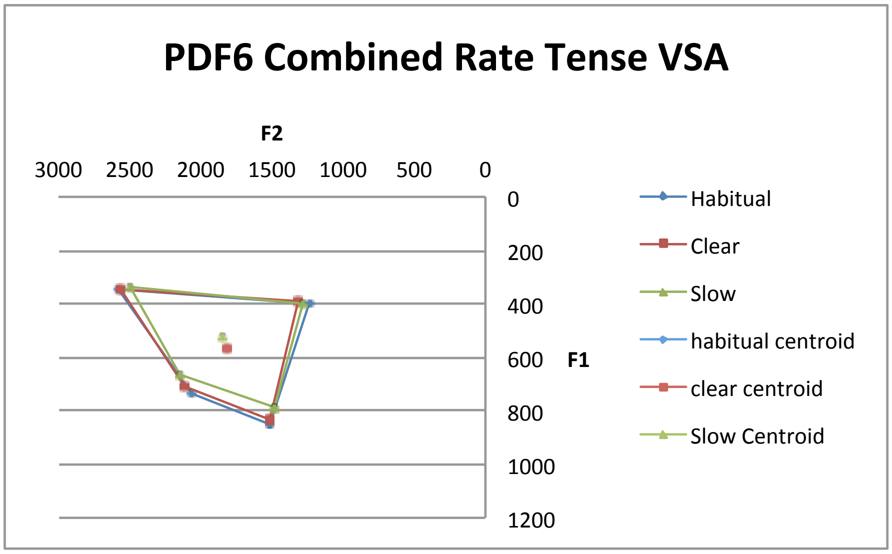
Parkinson's Female 5 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

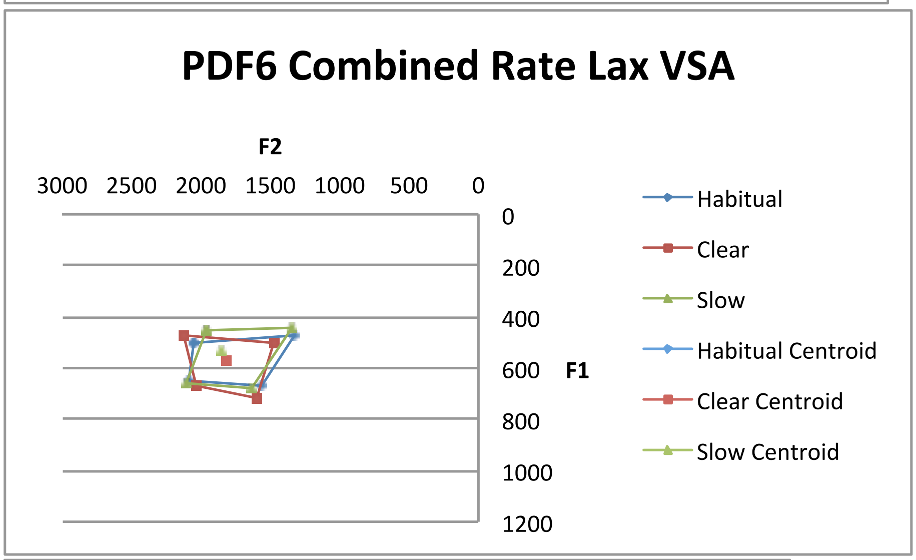


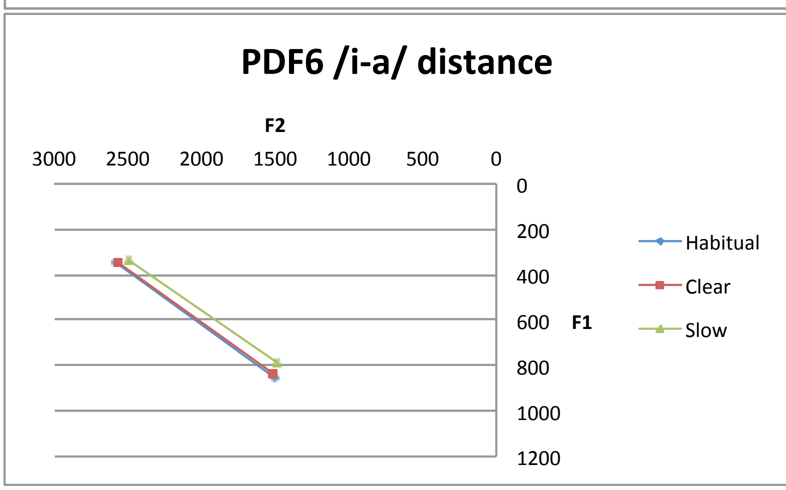




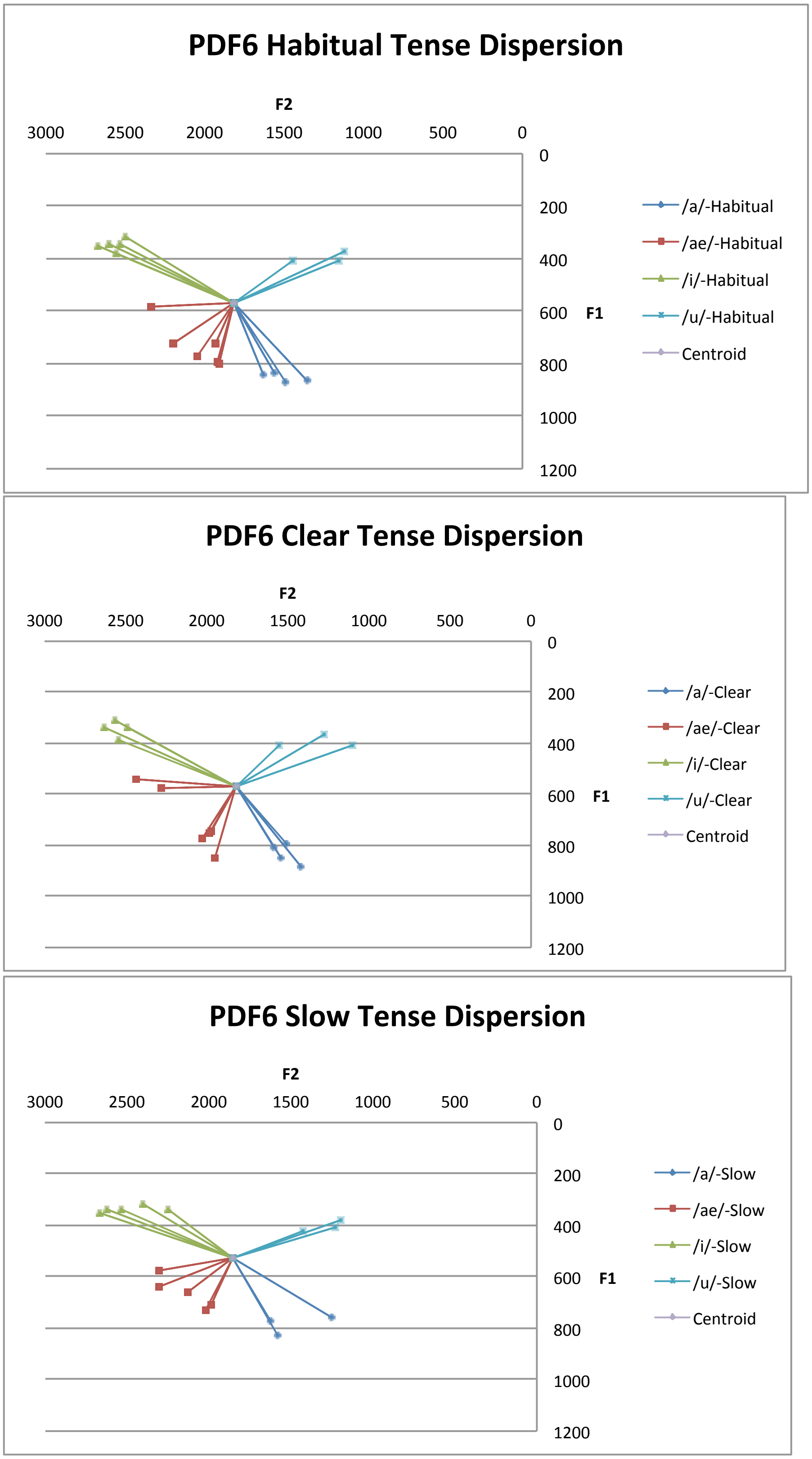
Parkinson's Female 5 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).



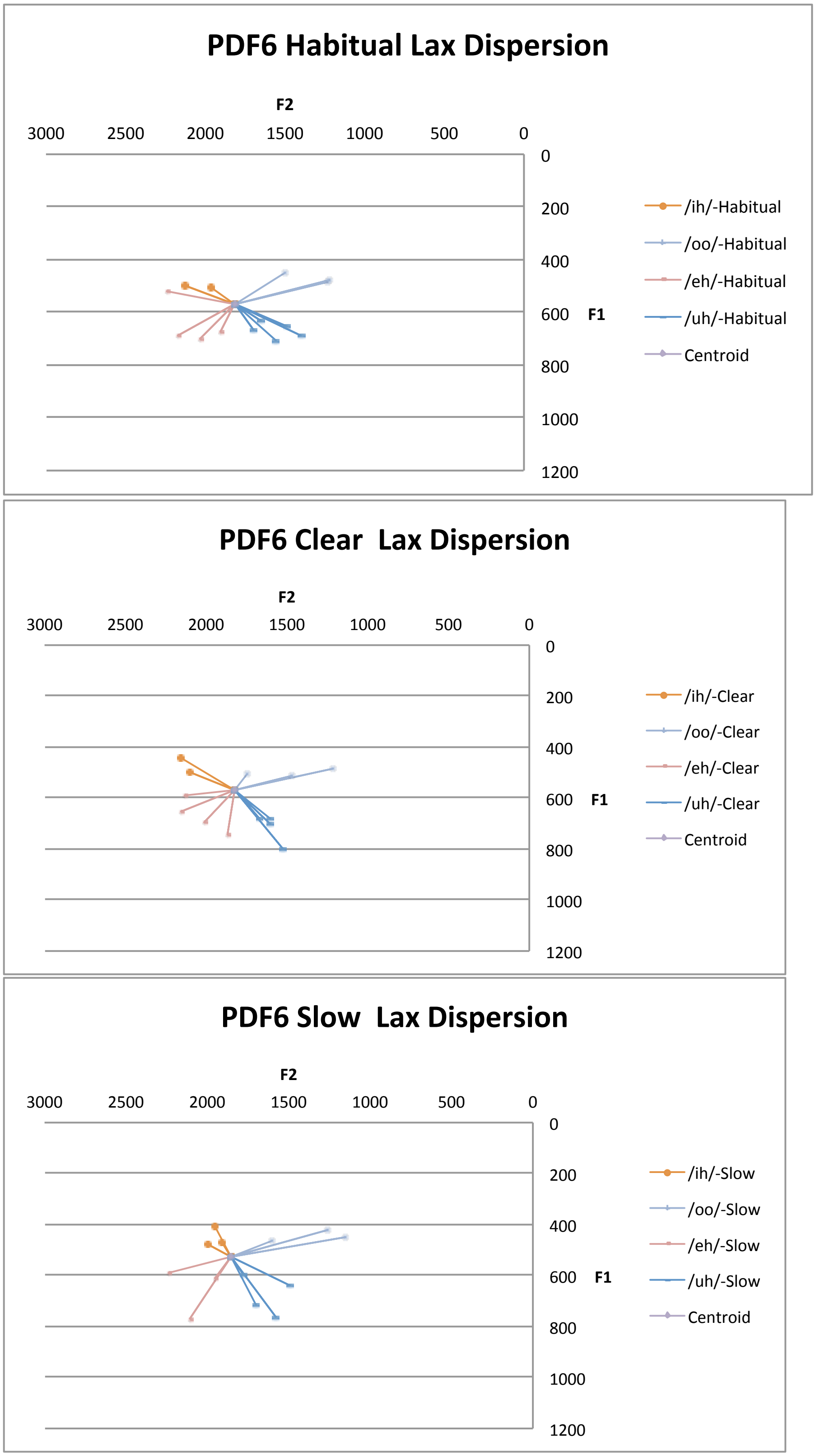




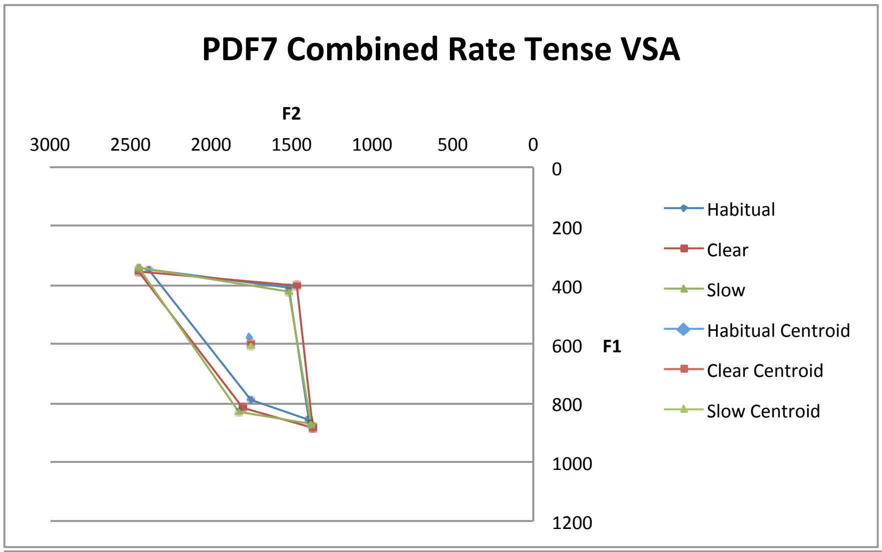
Parkinson's Female 6 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

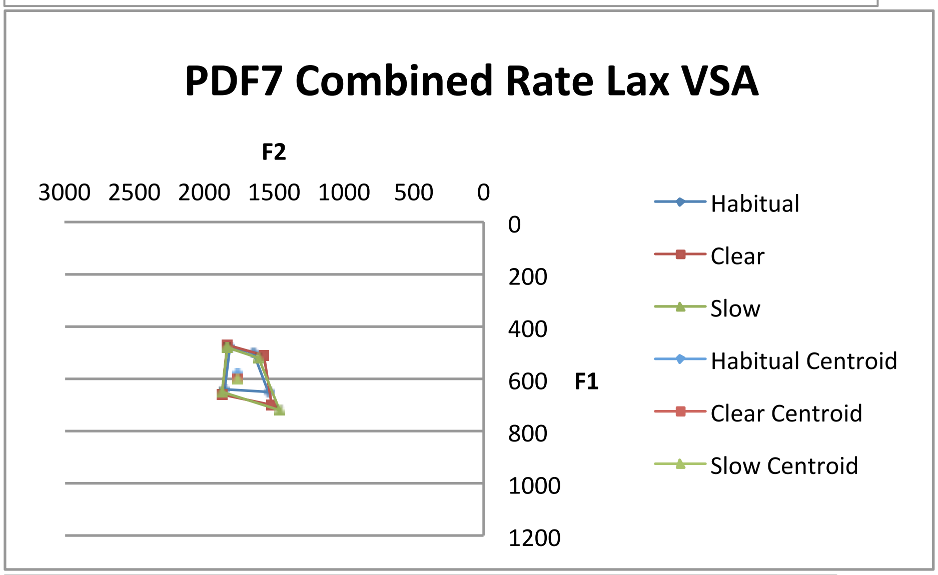


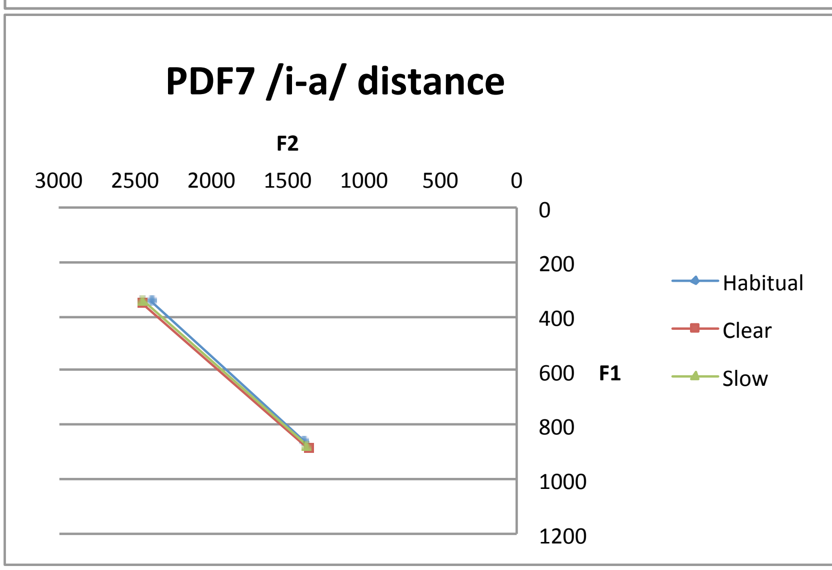
Parkinson's Female 6 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).



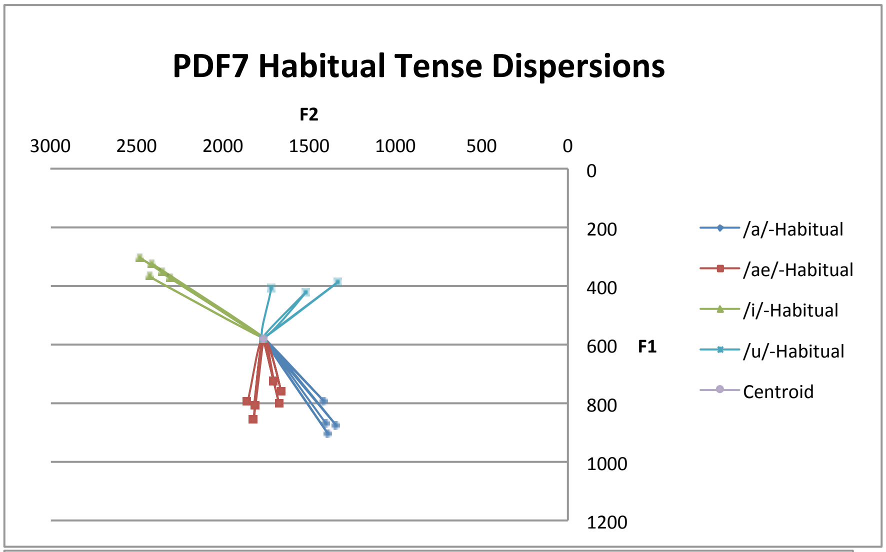
Parkinson's Female 6 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

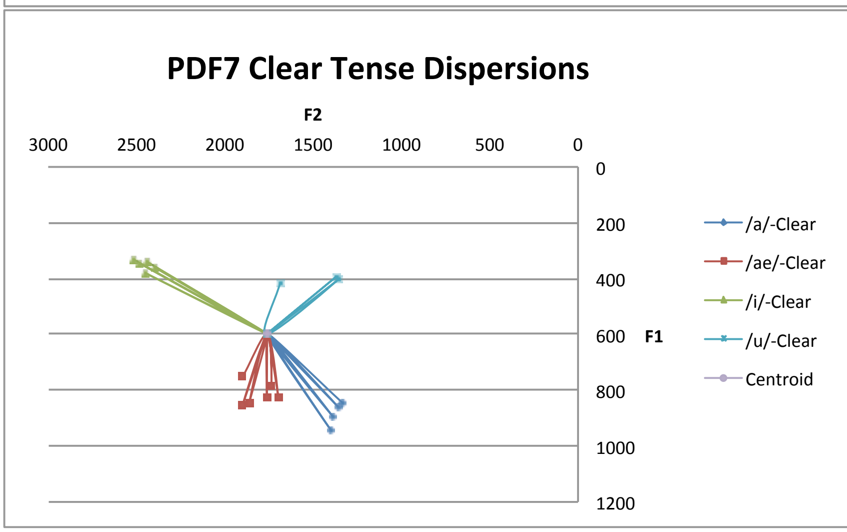


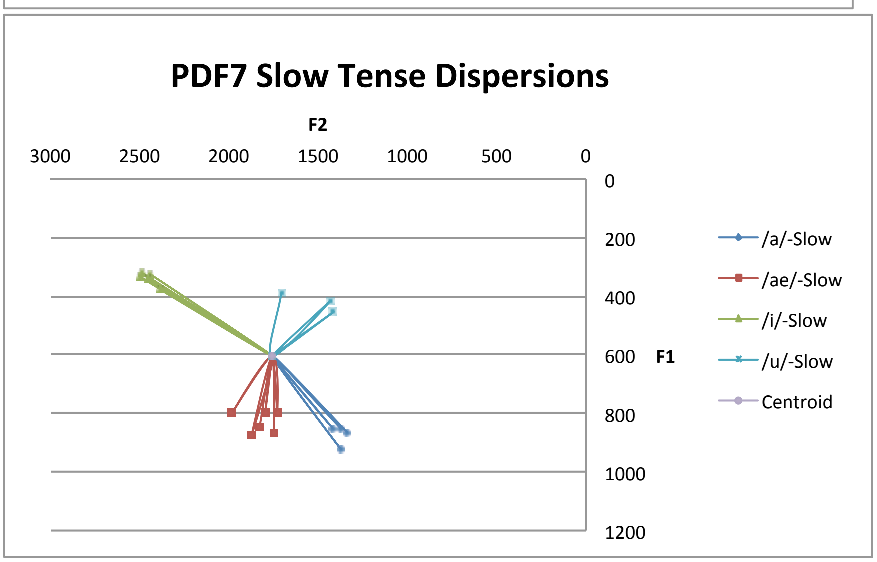




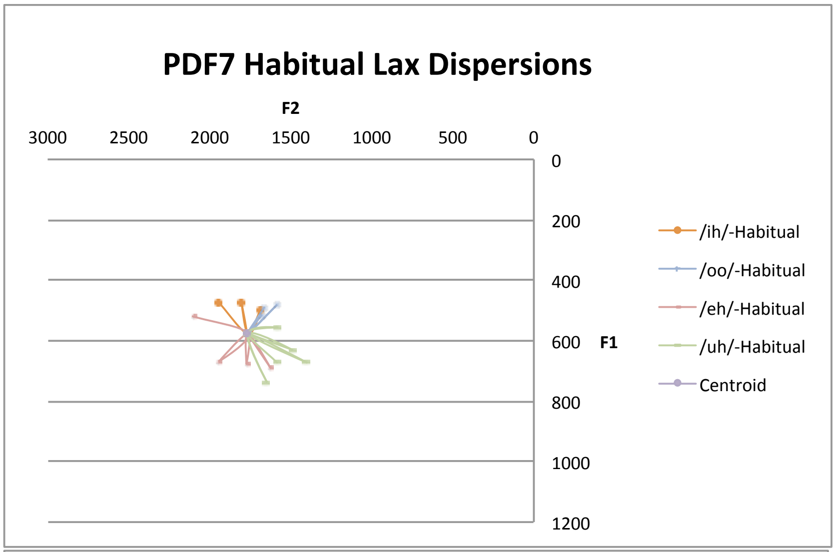
Parkinson's Female 7 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

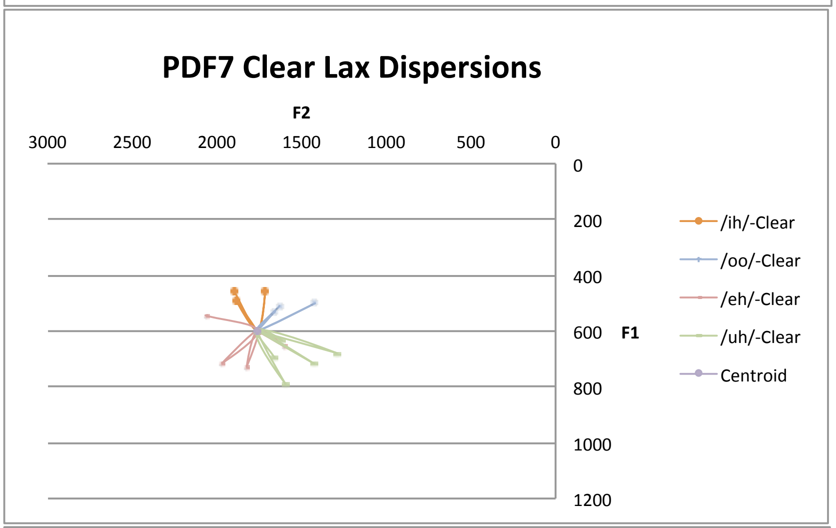


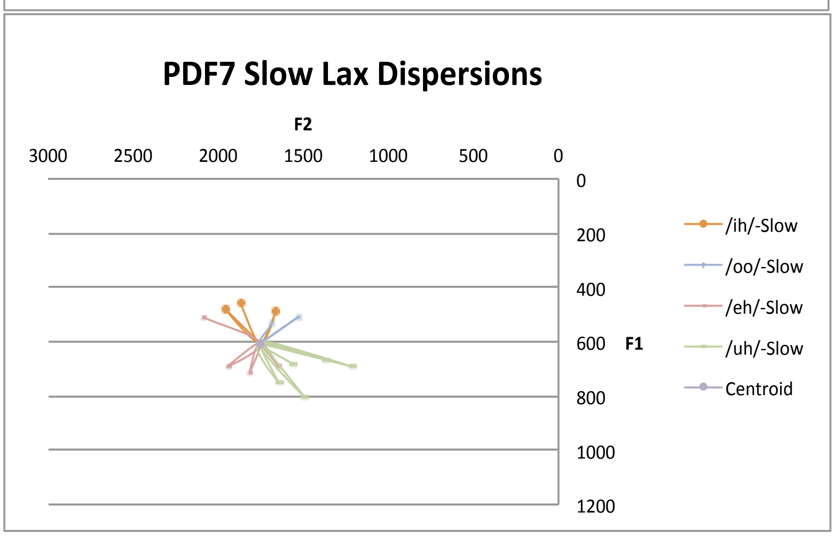




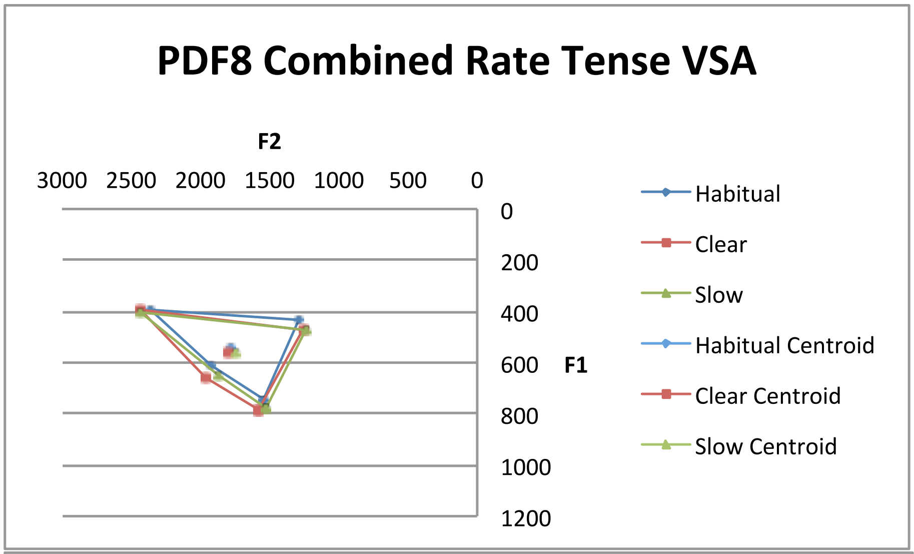
Parkinson's Female 7 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

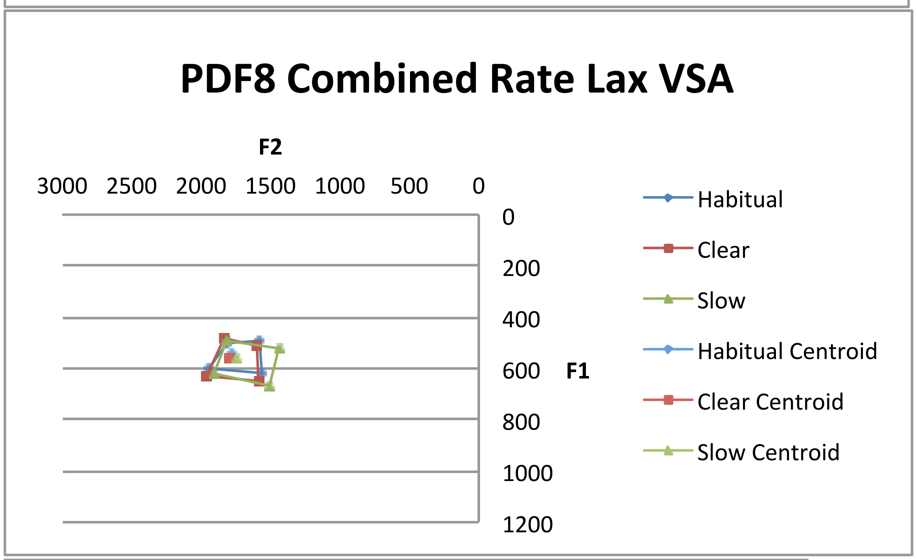


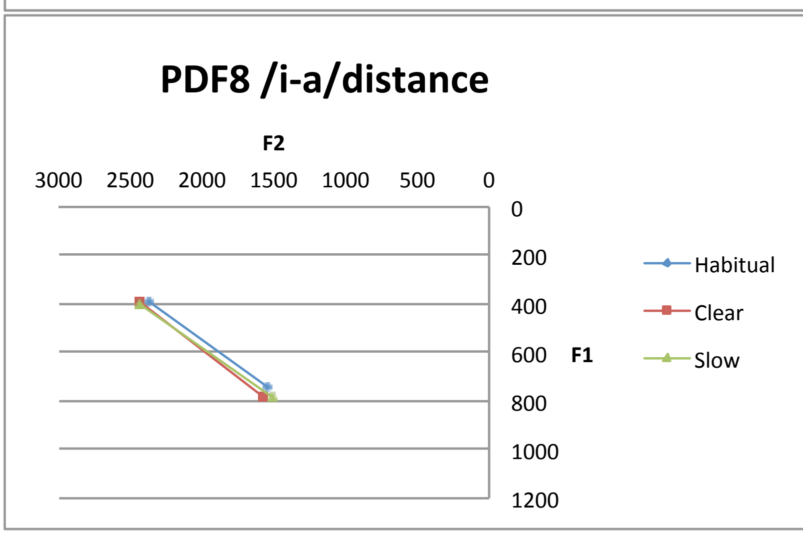




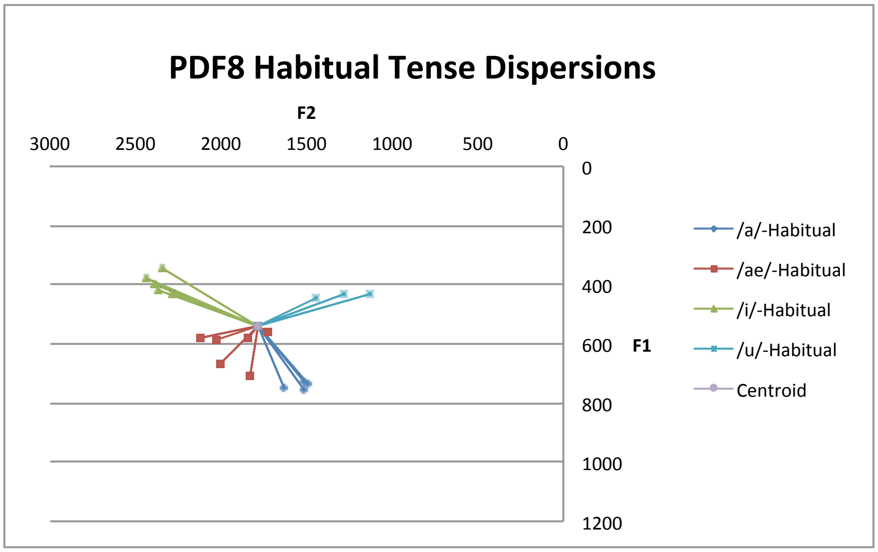
Parkinson's Female 7 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

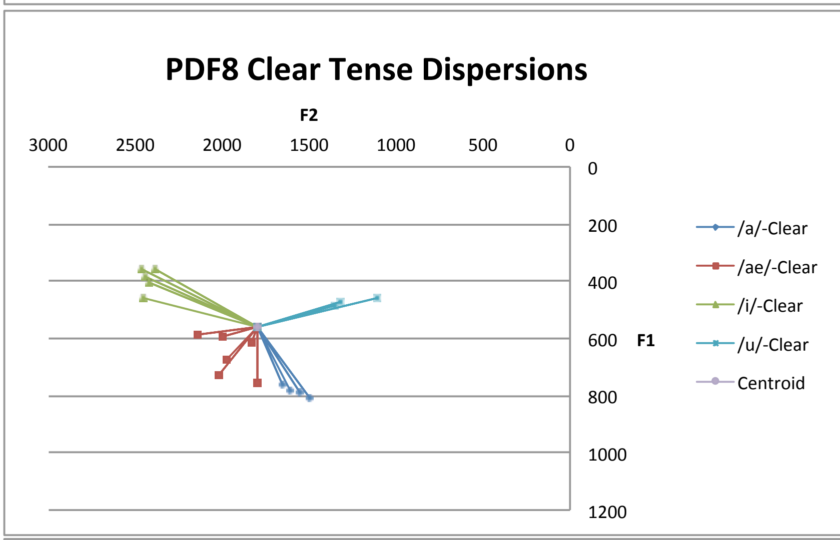


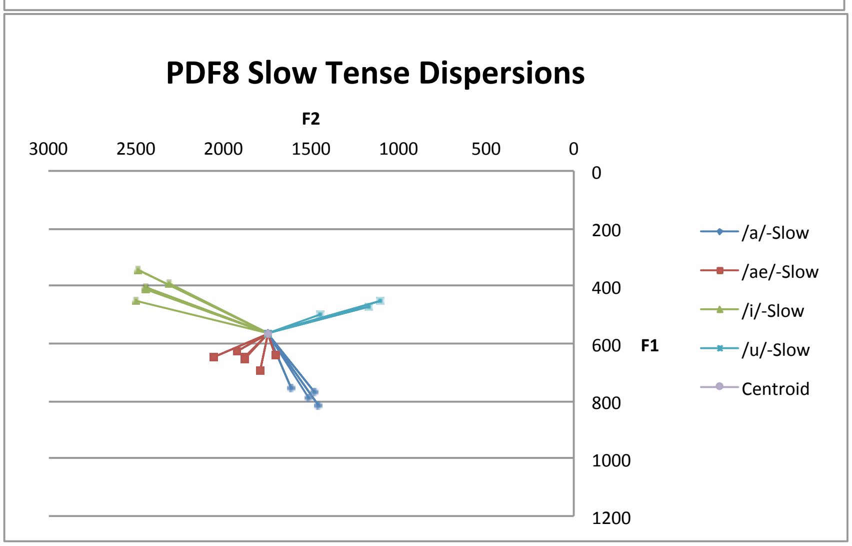




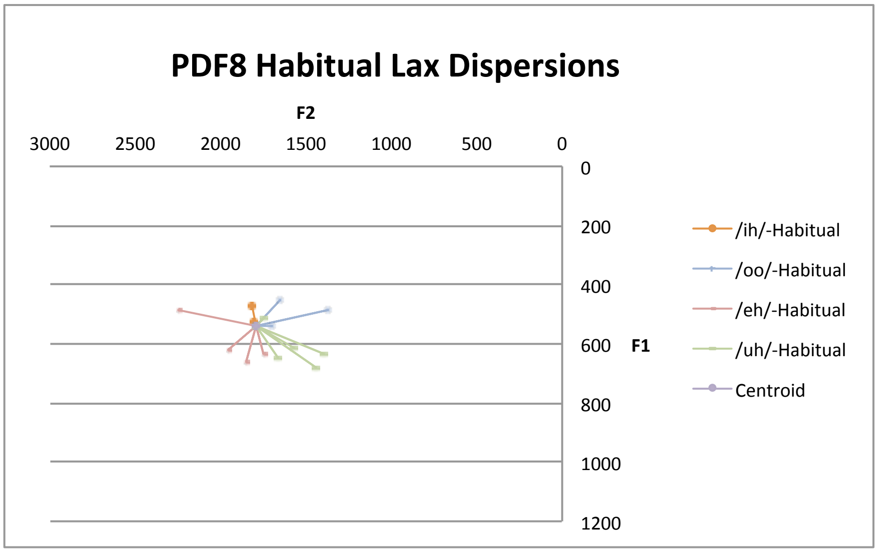
Parkinson's Female 8 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

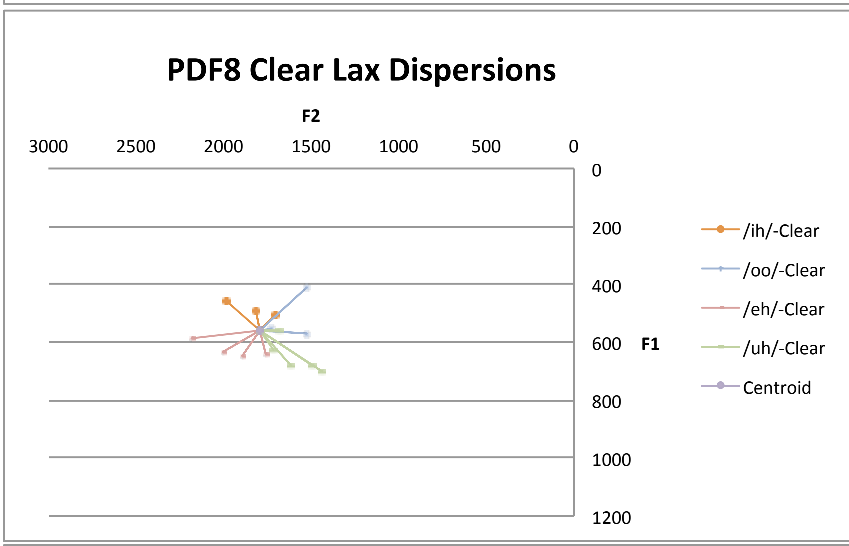


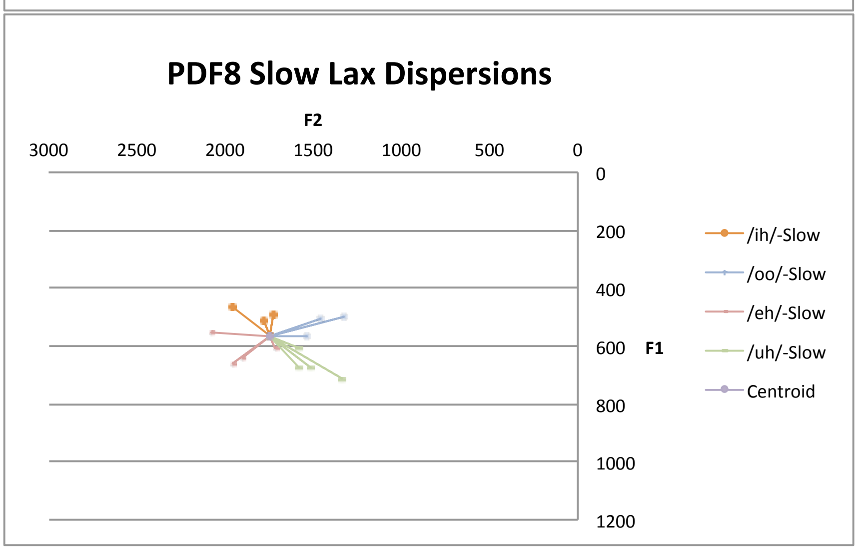




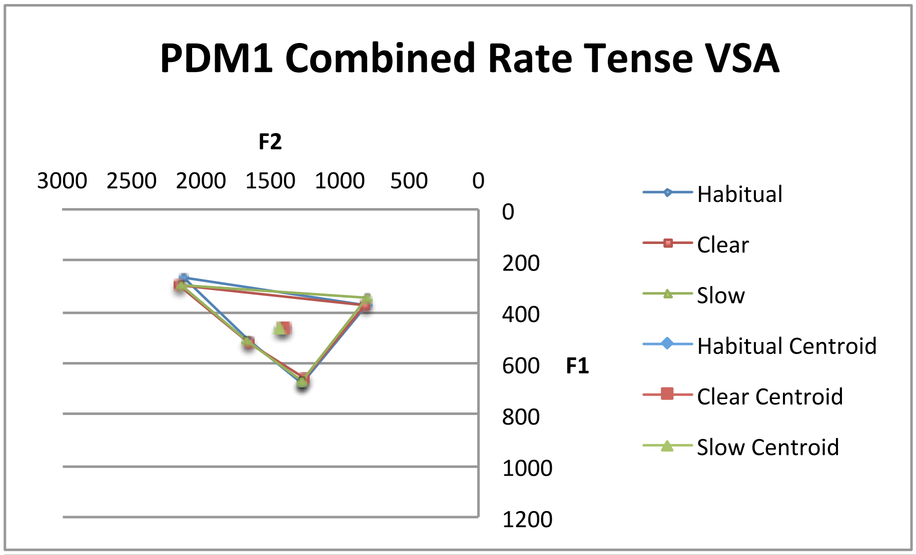
Parkinson's Female 8 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

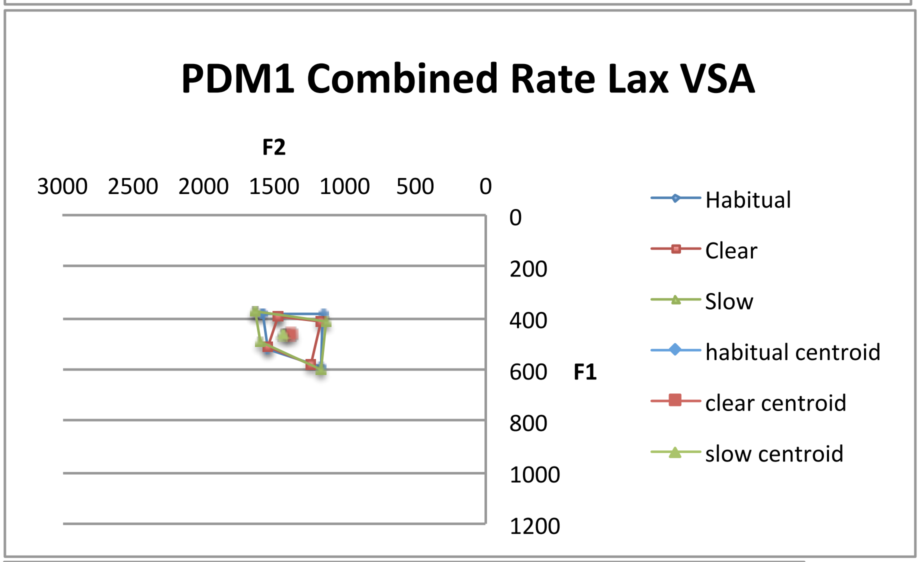


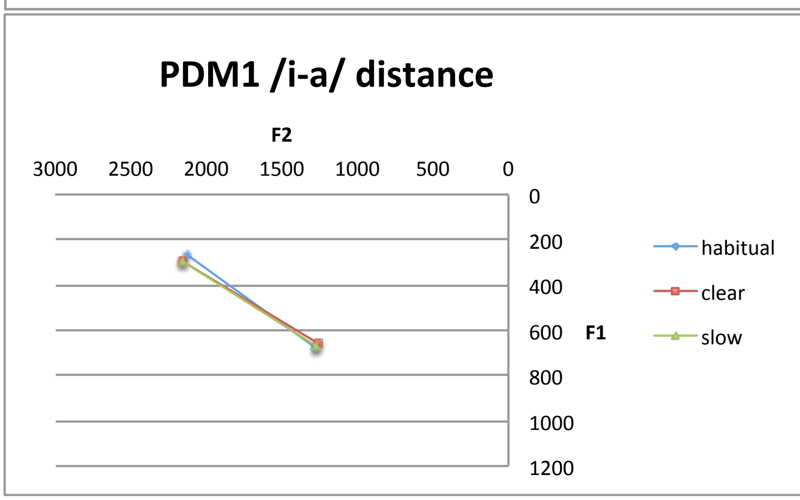




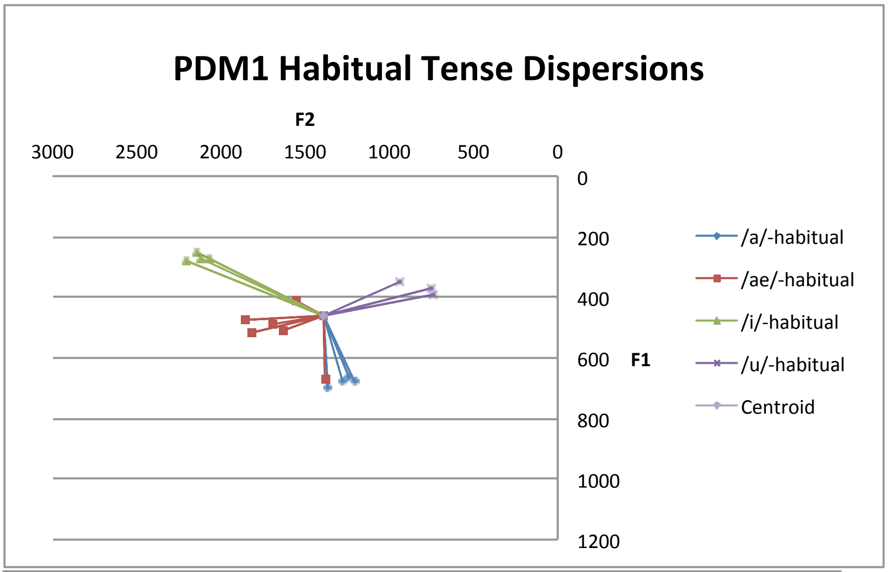
Parkinson's Female 8 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

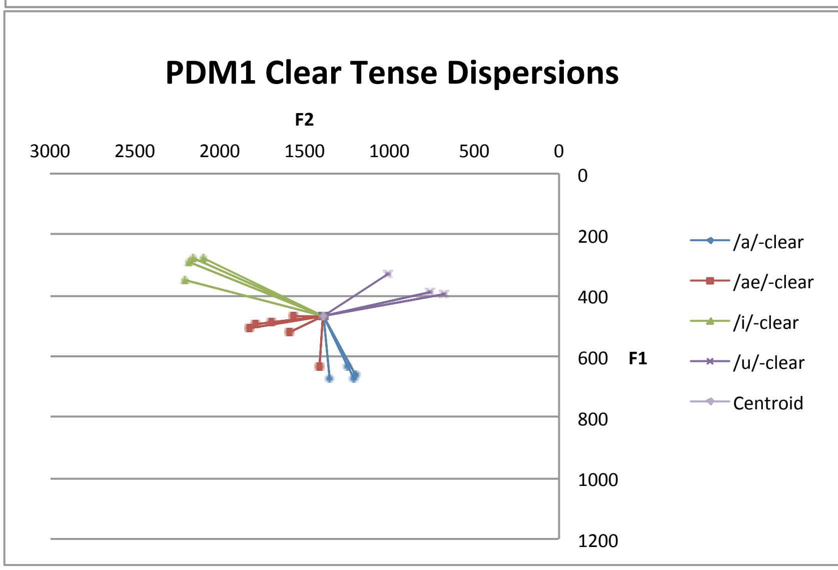


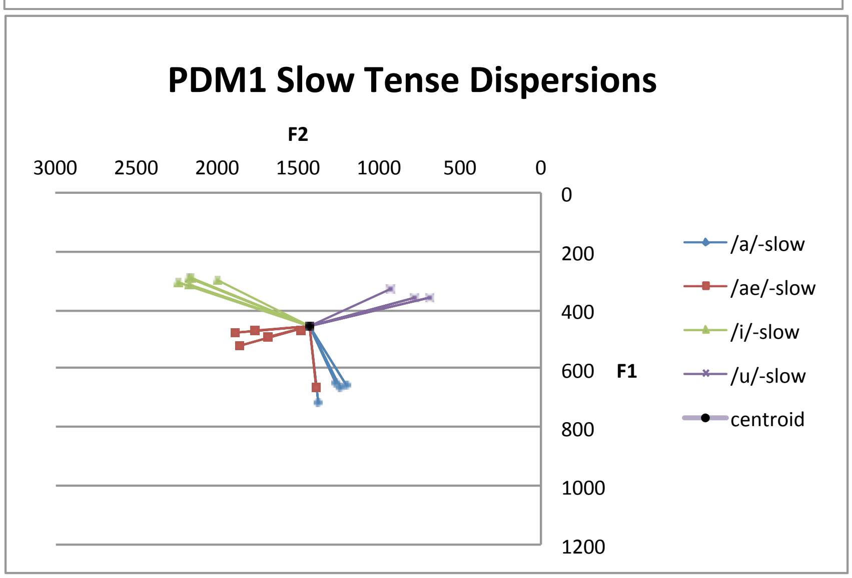




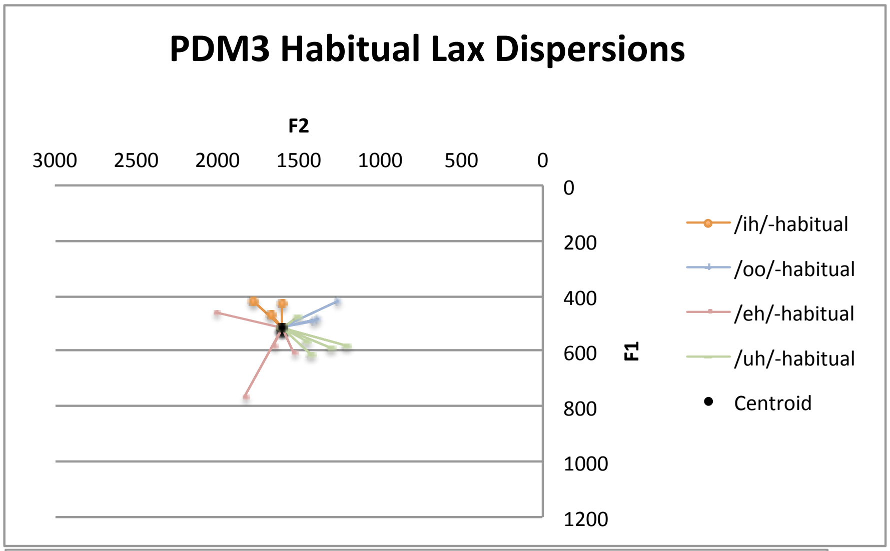
Parkinson's Male 1 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

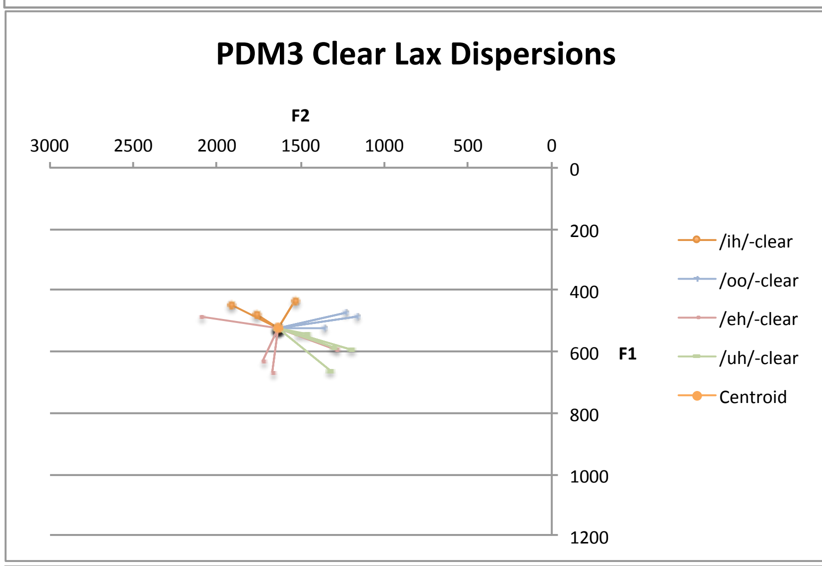


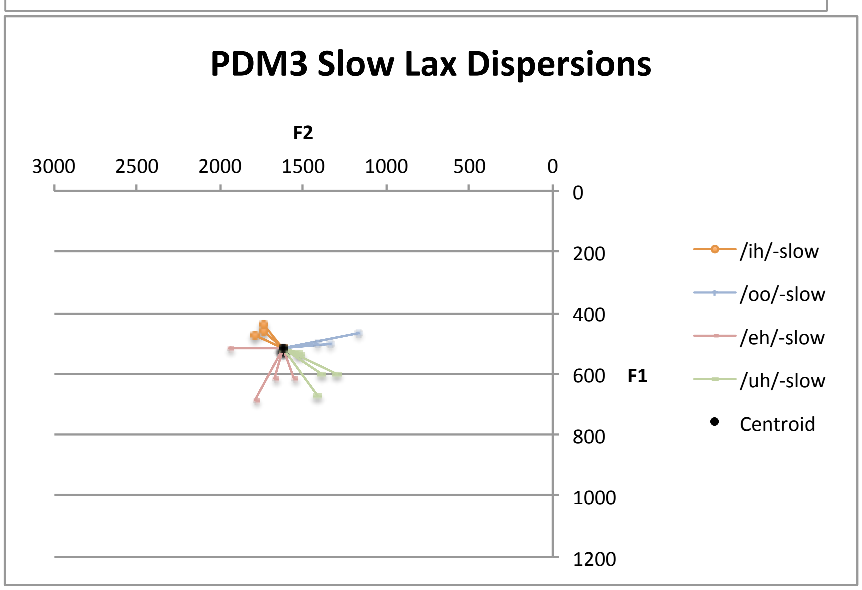




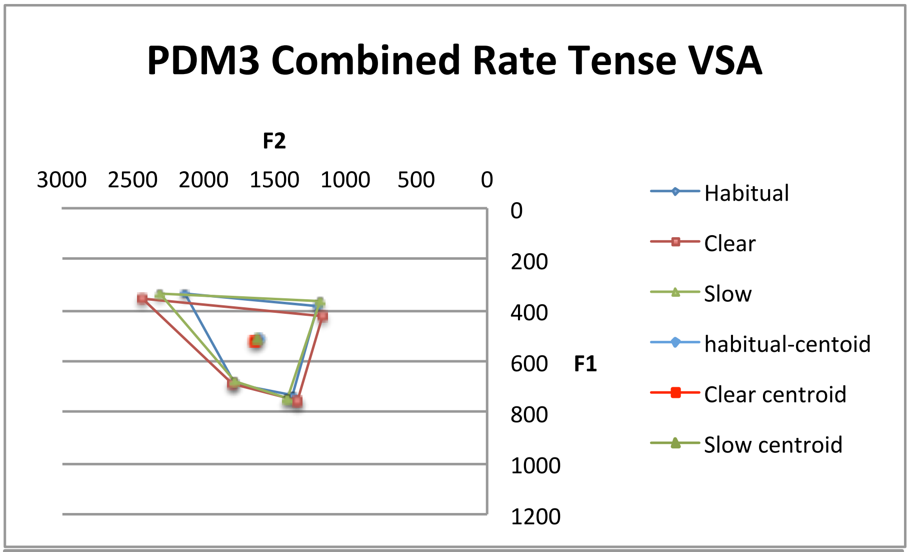
Parkinson's Male 1 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

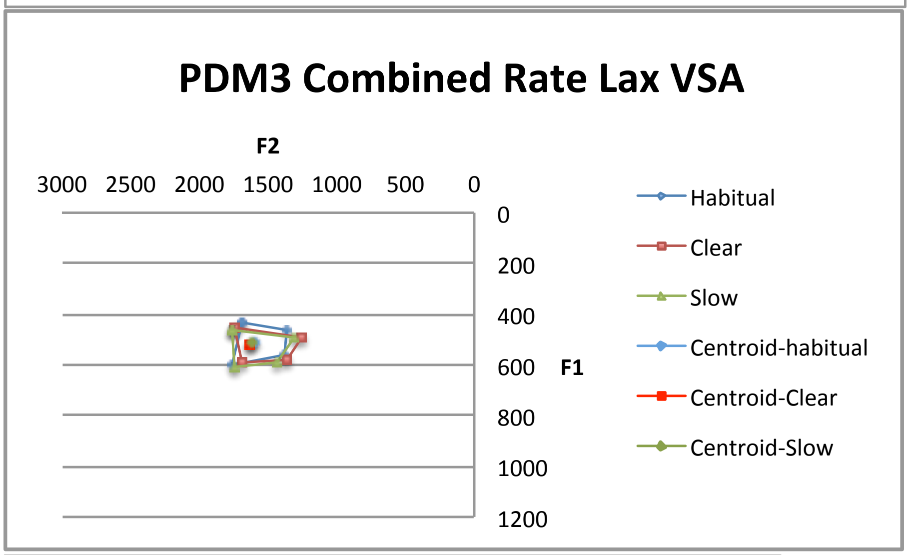


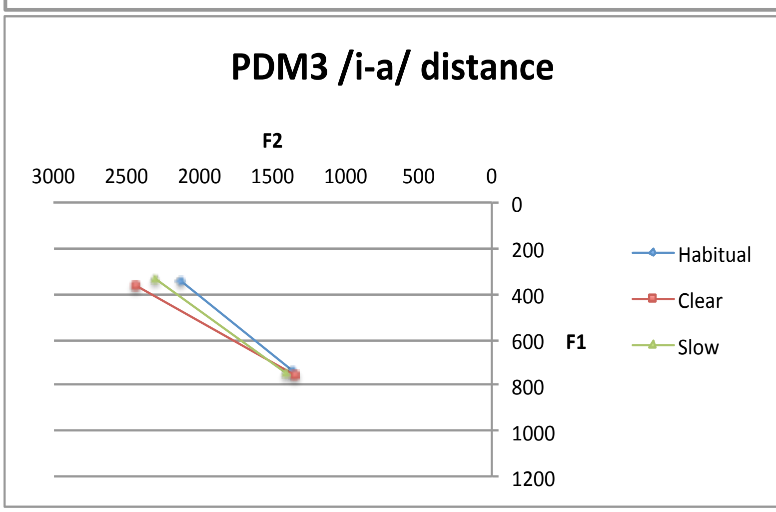




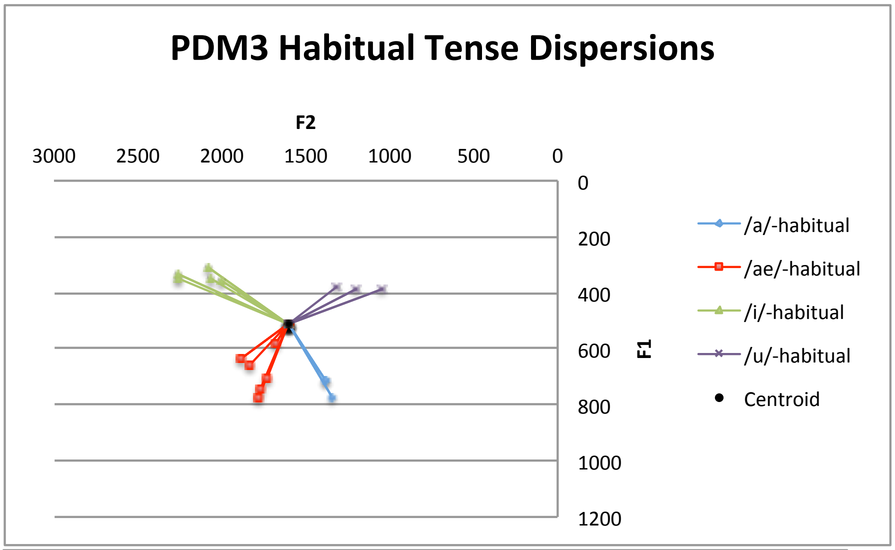
Parkinson's Male 1 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

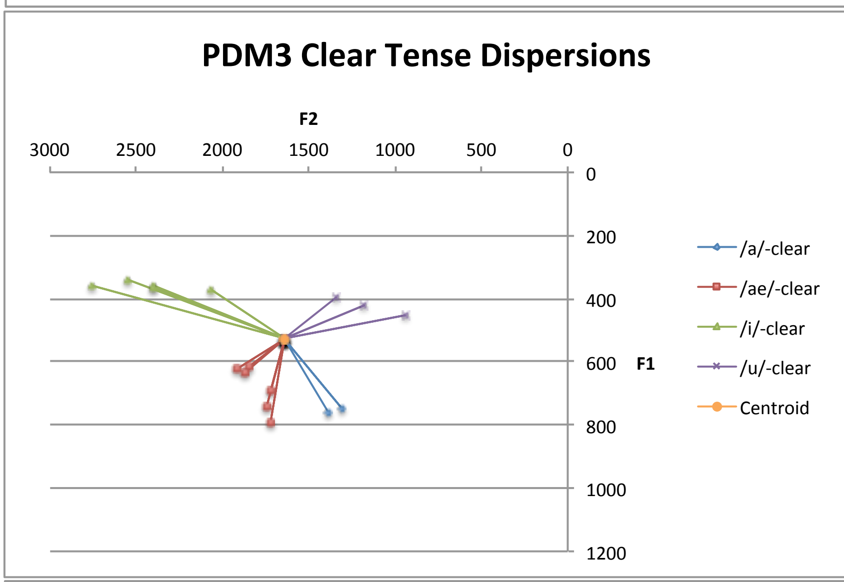


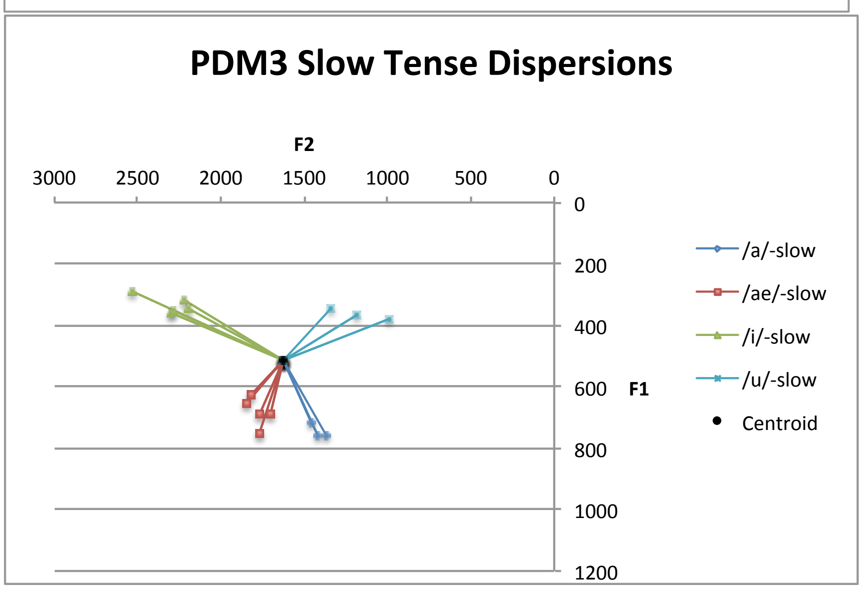




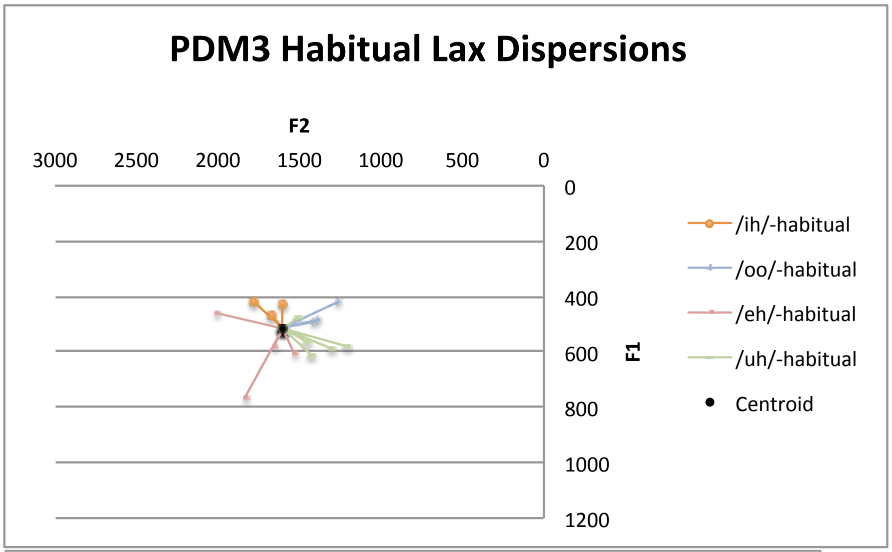
Parkinson's Male 3 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

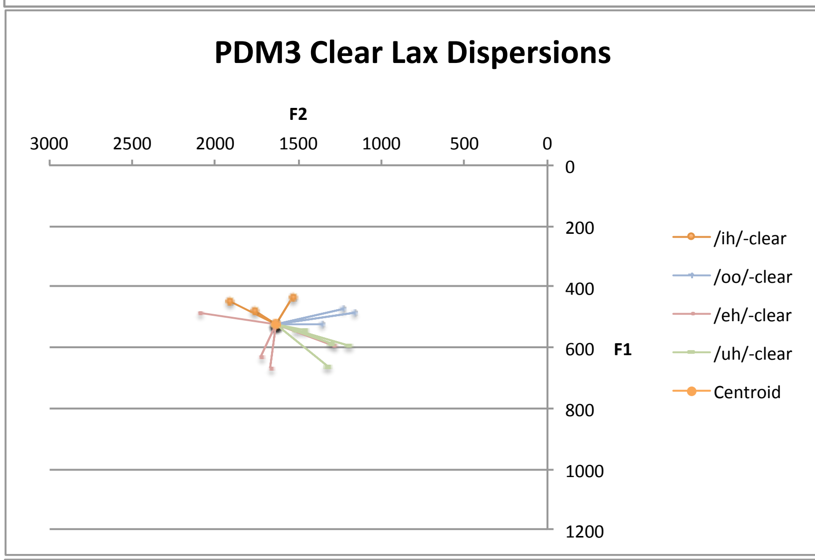


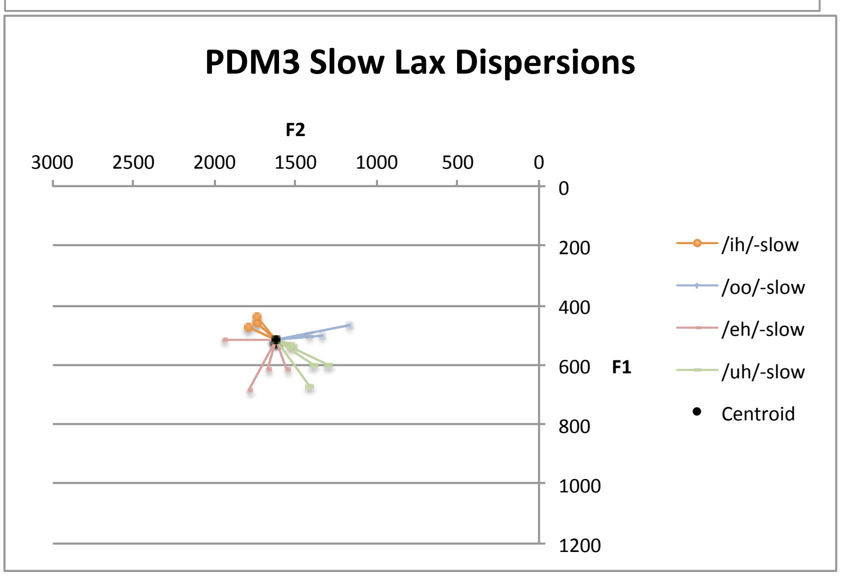




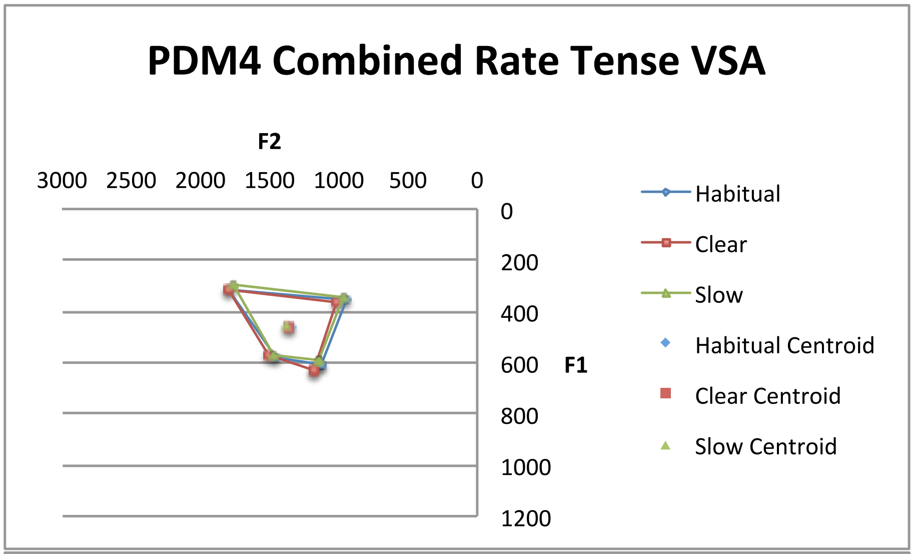
Parkinson's Male 3 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

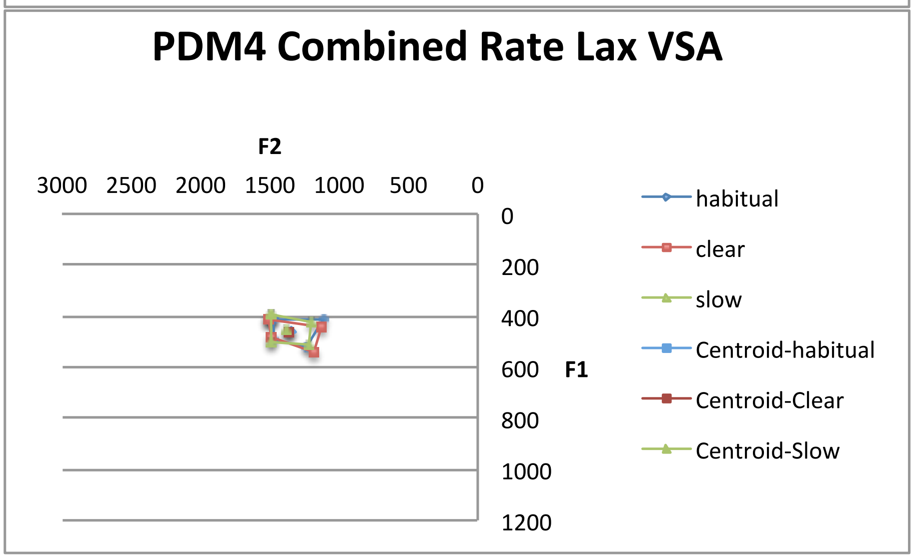


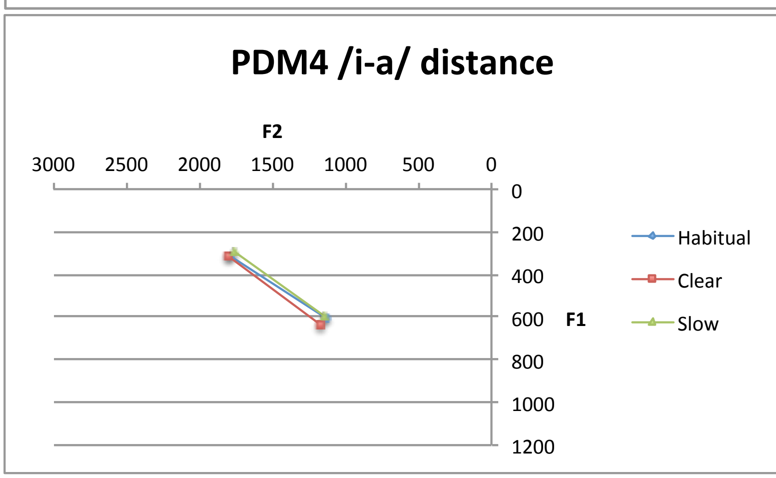




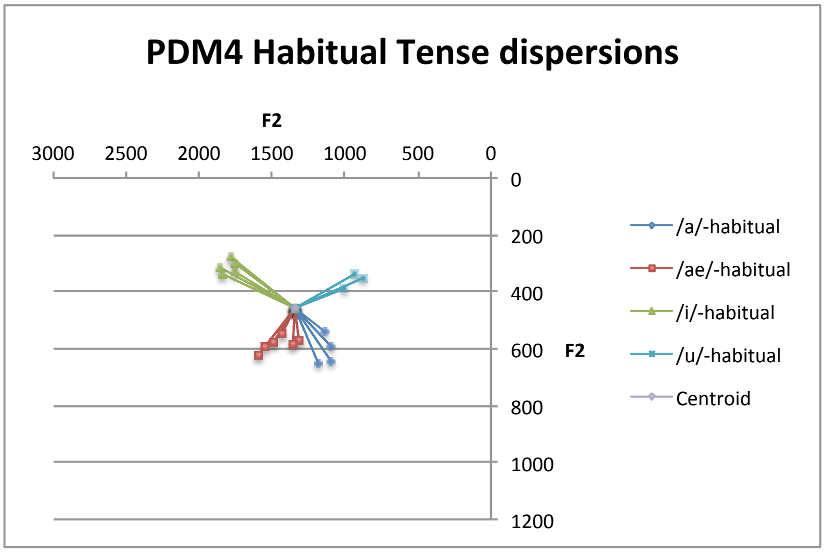
Parkinson's Male 3 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

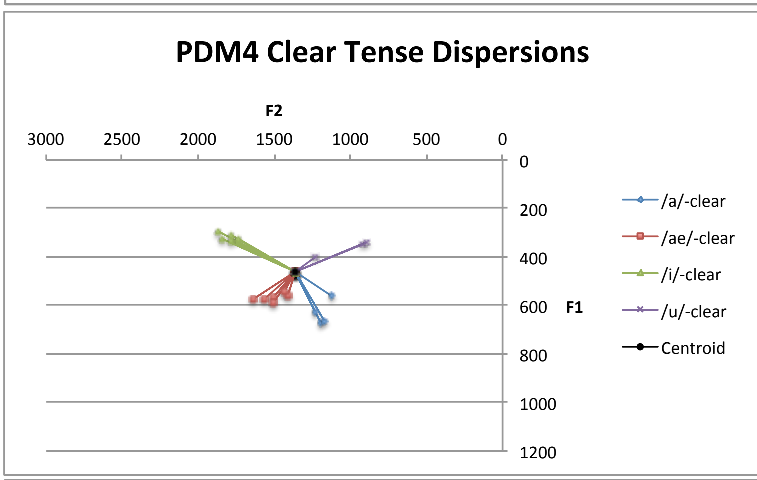


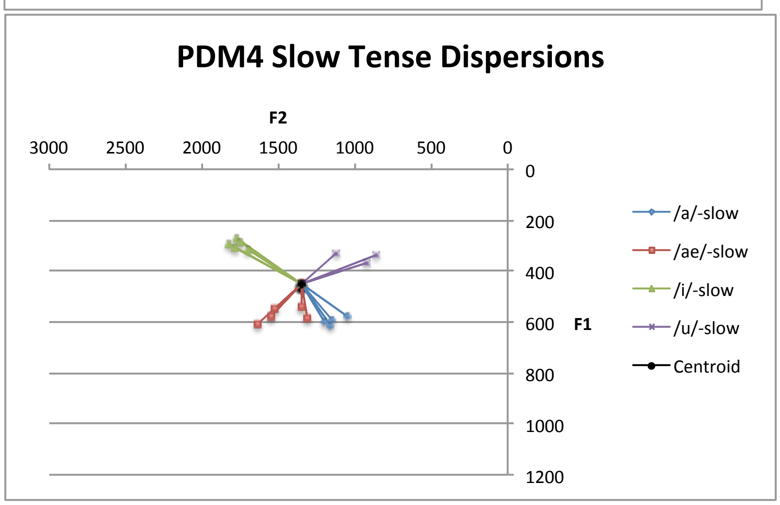




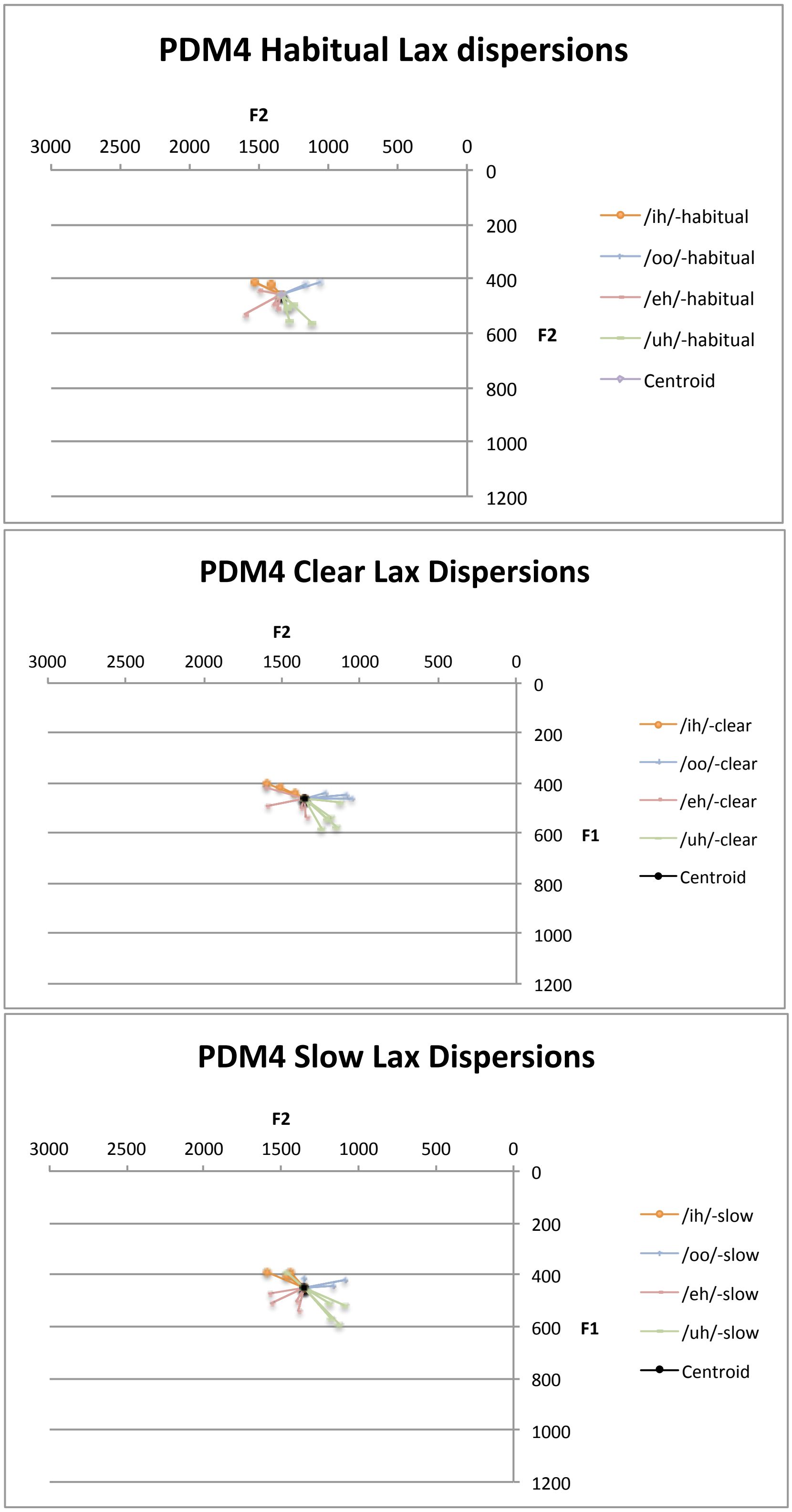
Parkinson's Male 4 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.



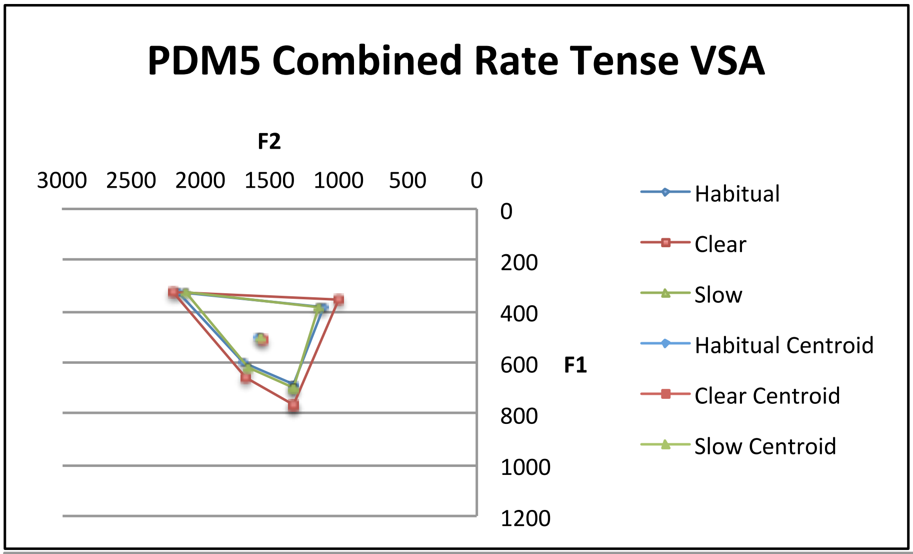


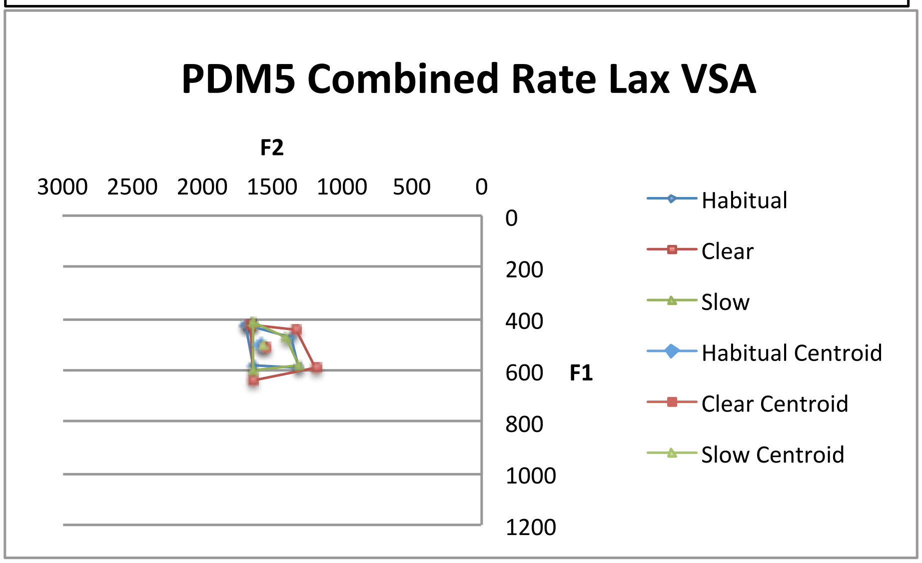


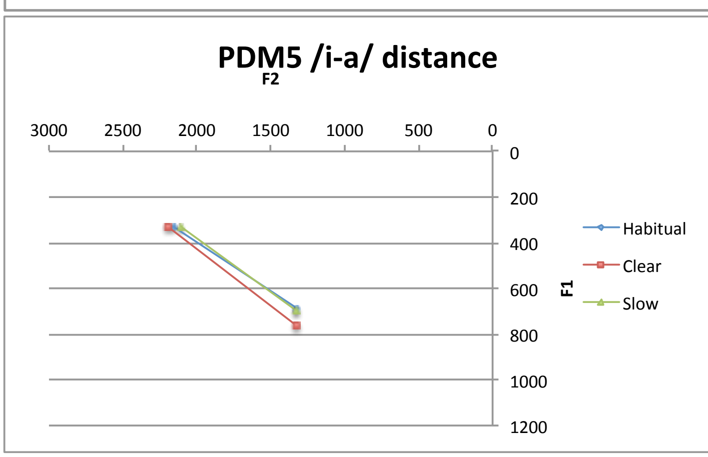
Parkinson's Male 4 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).



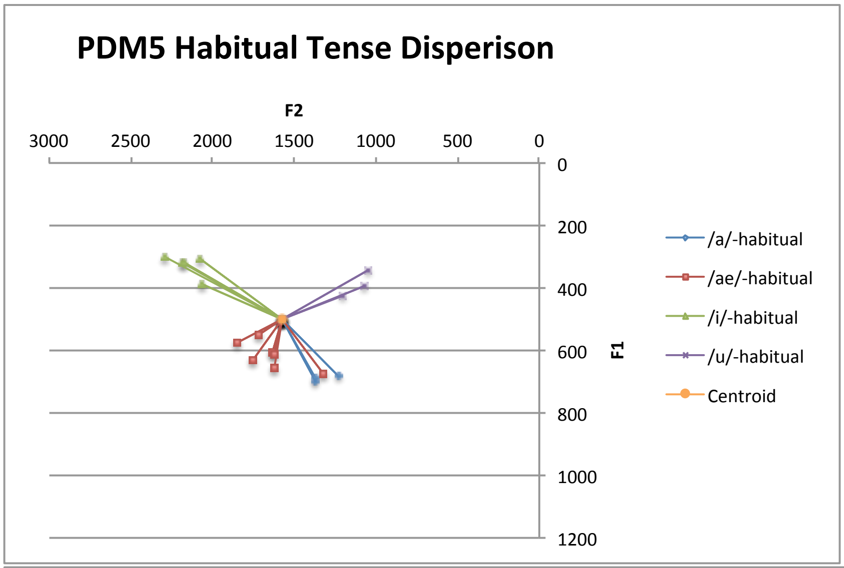
Parkinson's Male 4 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

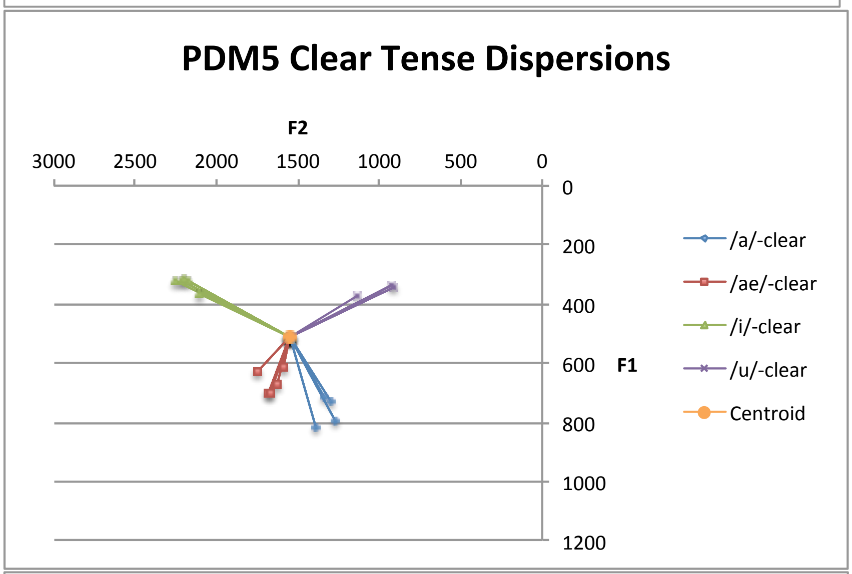


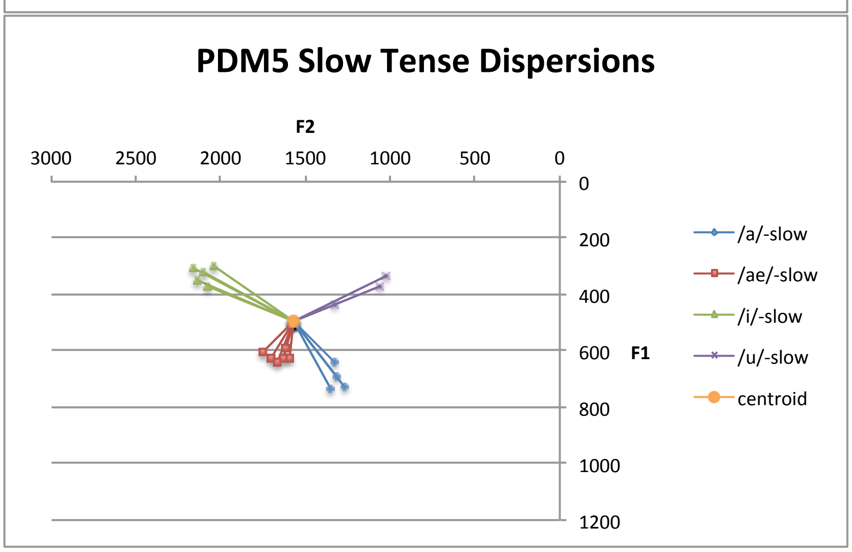




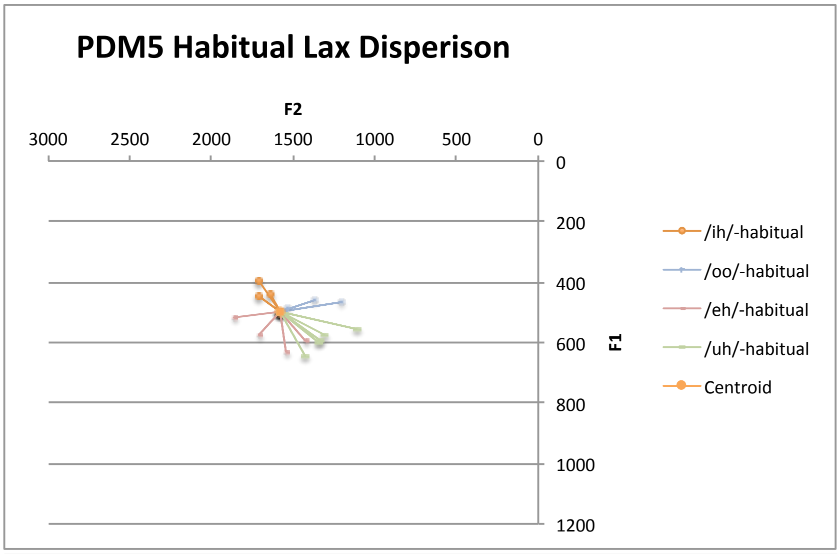
Parkinson's Male 5 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

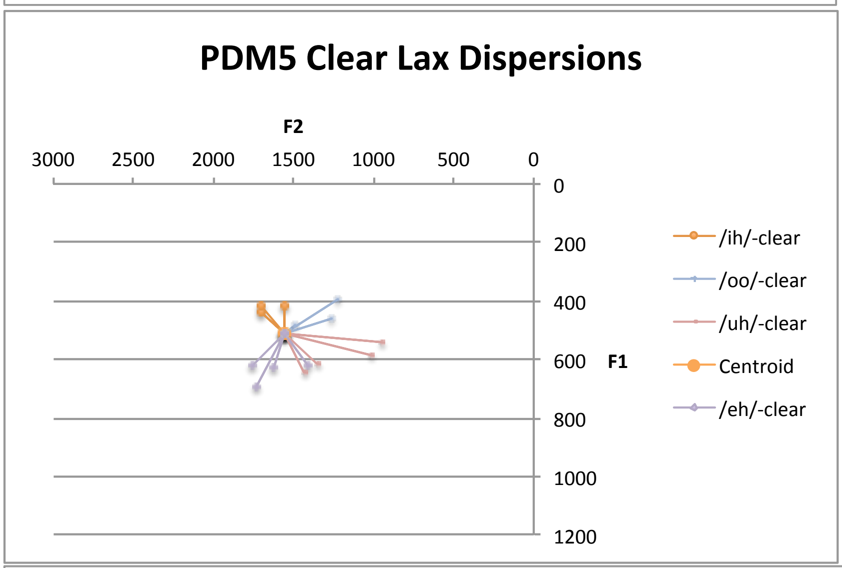


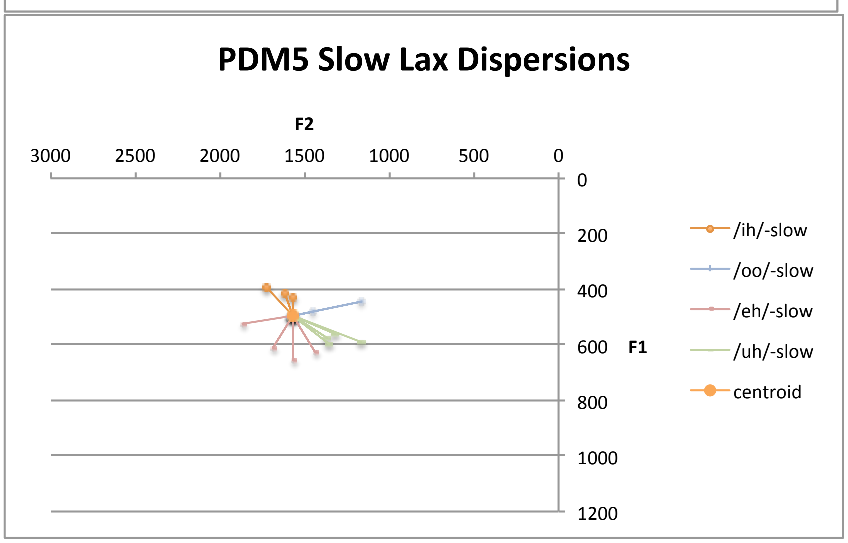




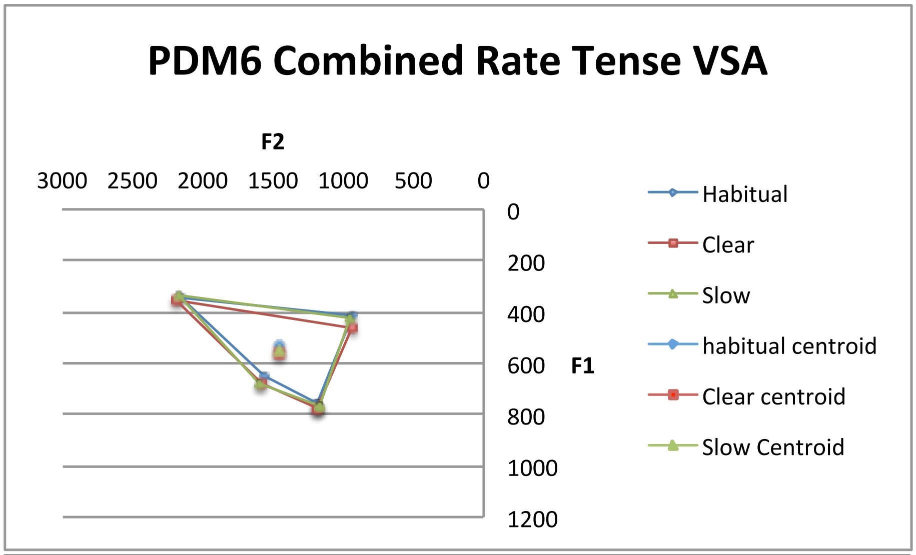
Parkinson's Male 5 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

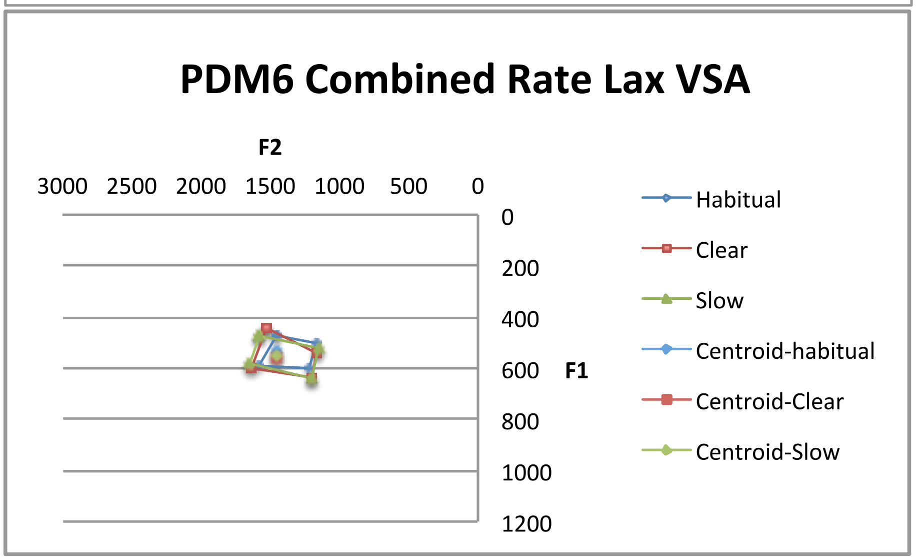


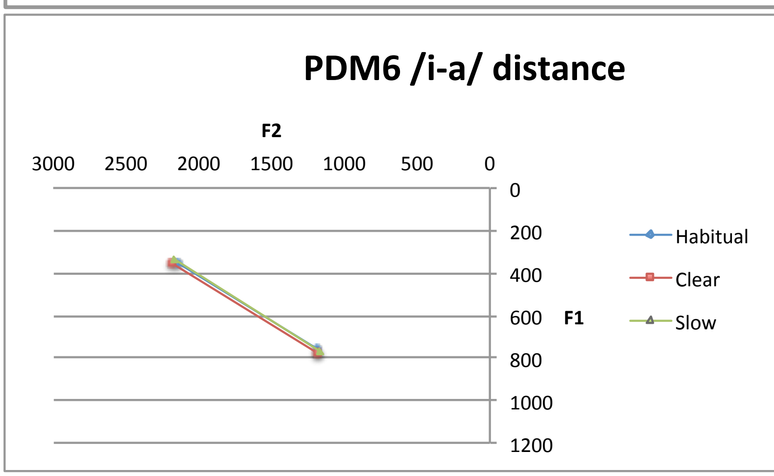




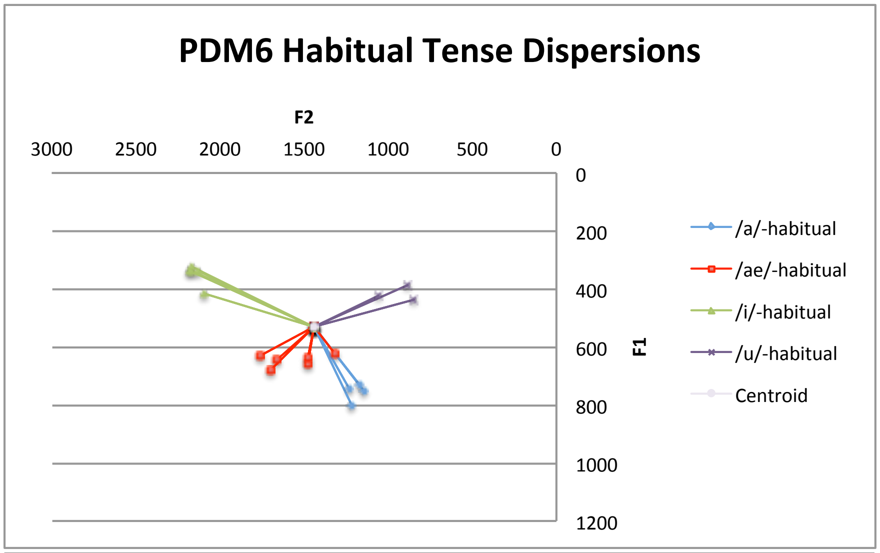
Parkinson's Male 5 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

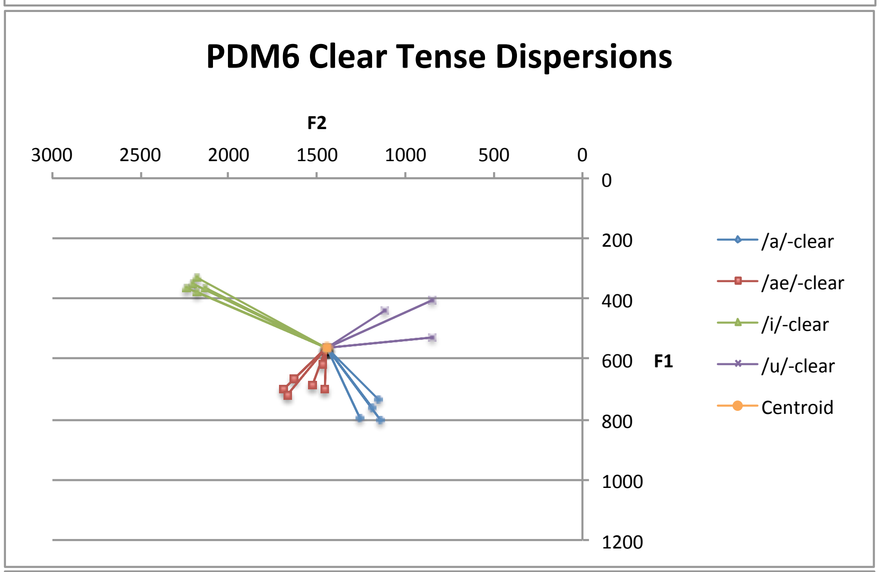


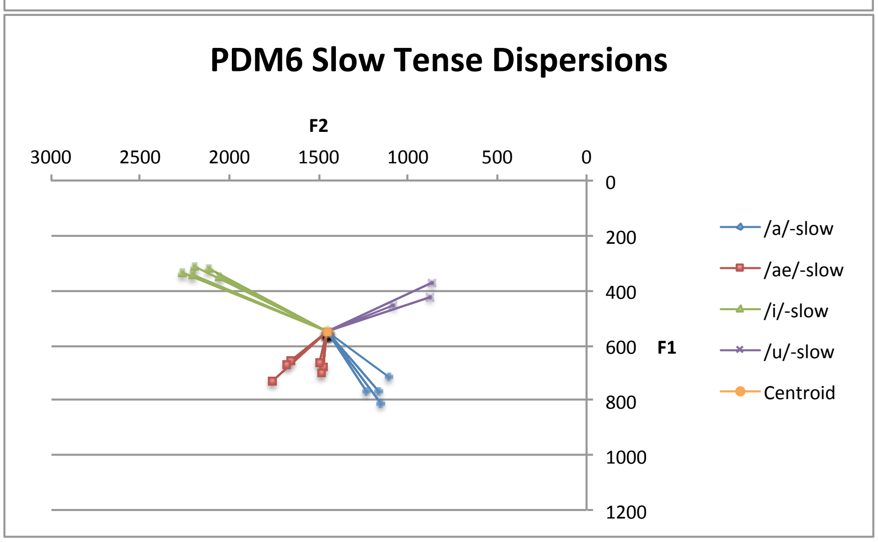




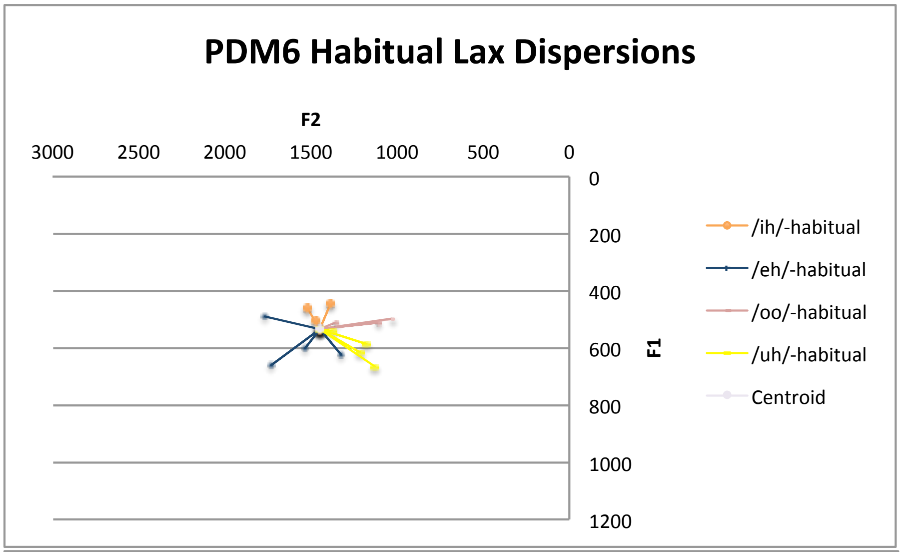
Parkinson's Male 6 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

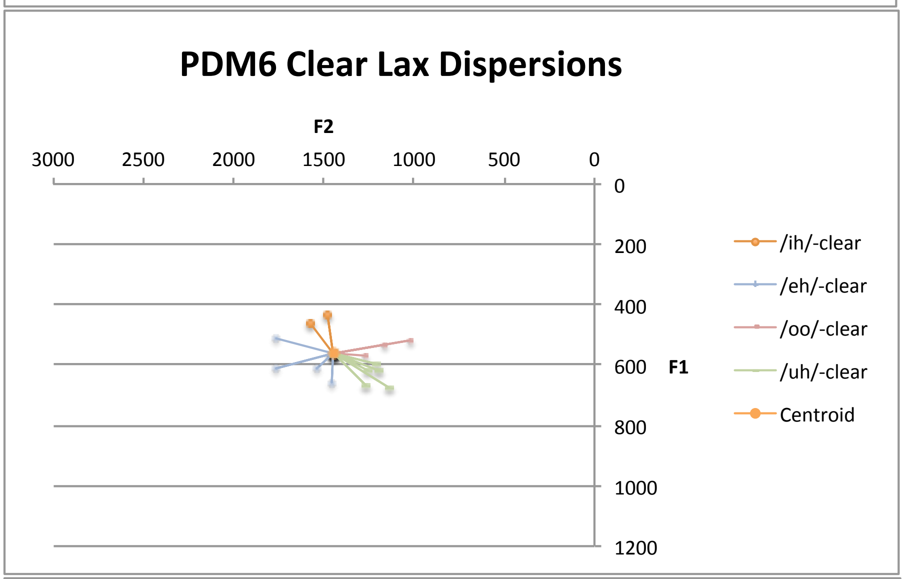


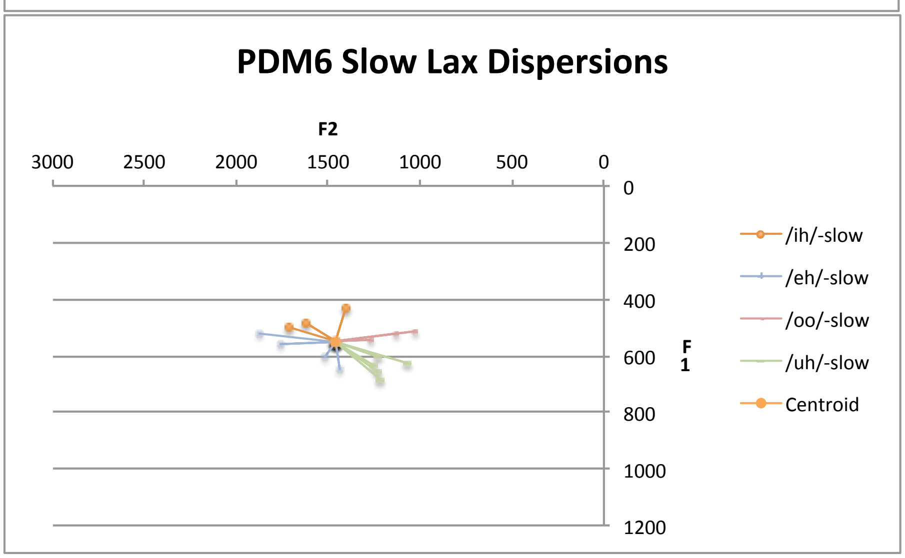




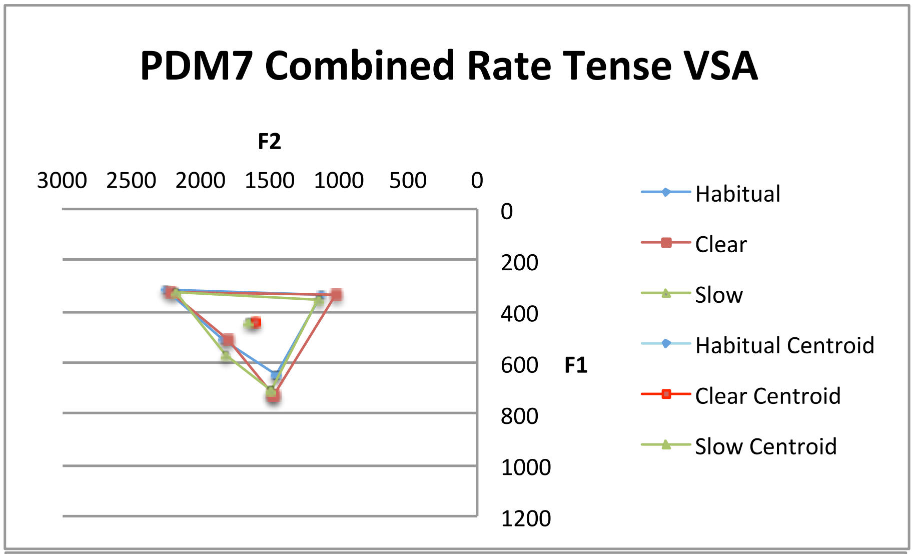
Parkinson's Male 6 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).

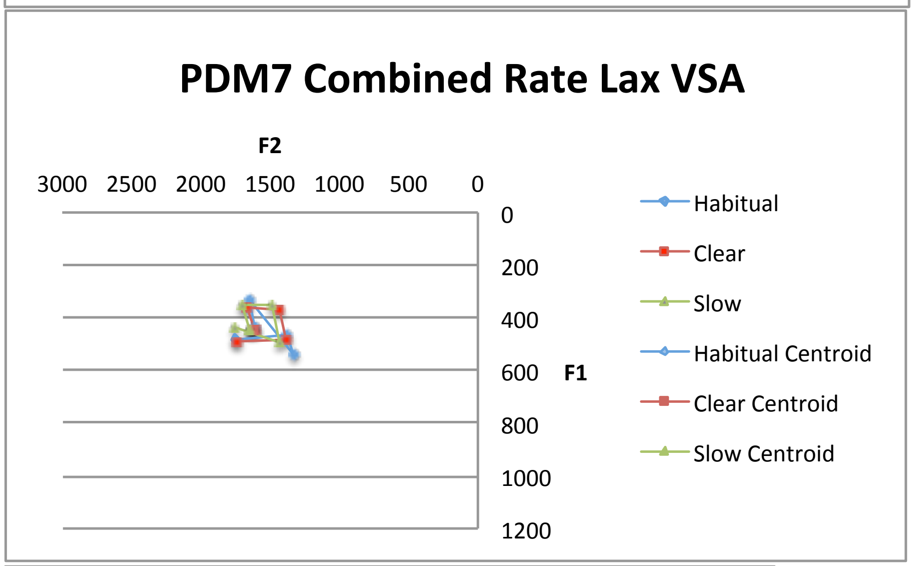


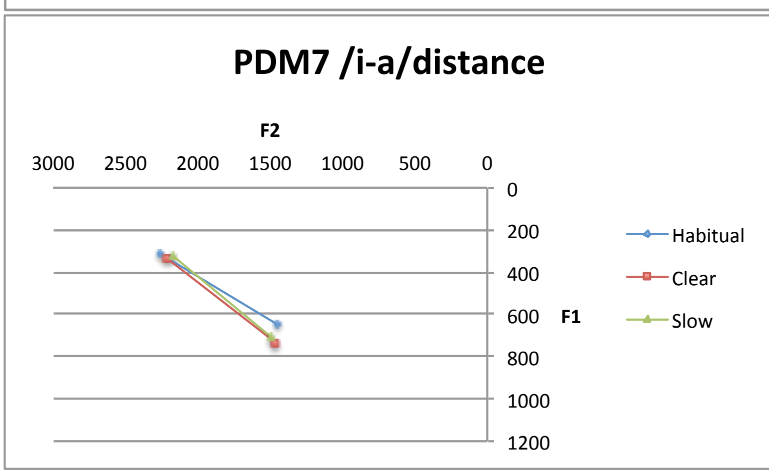




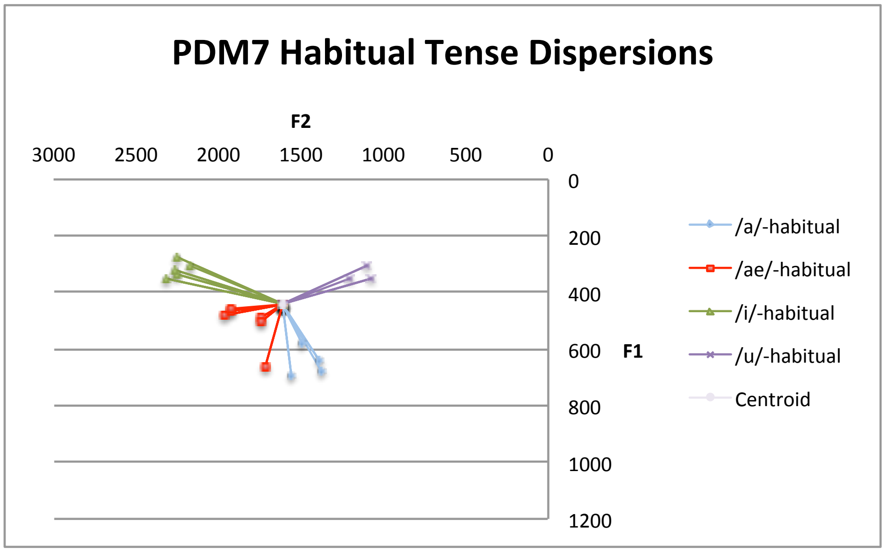
Parkinson's Male 6 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow).

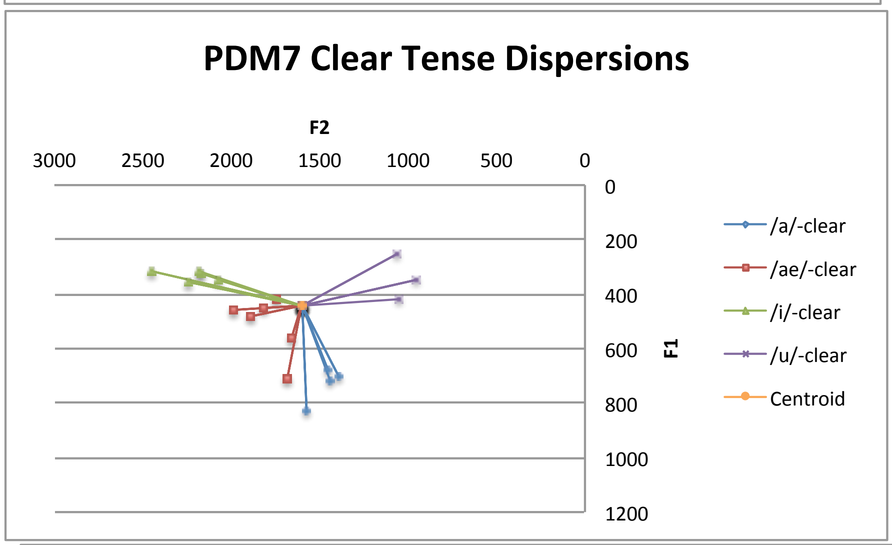


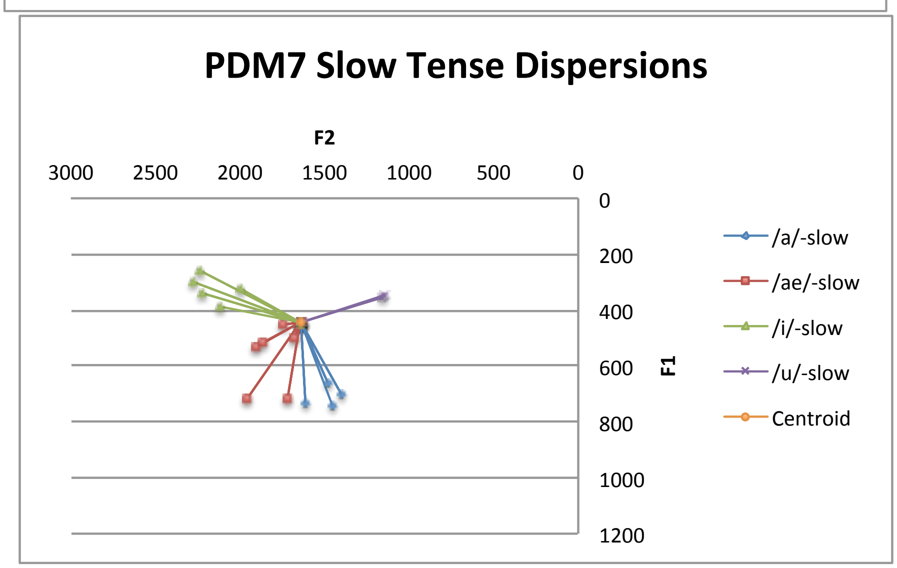




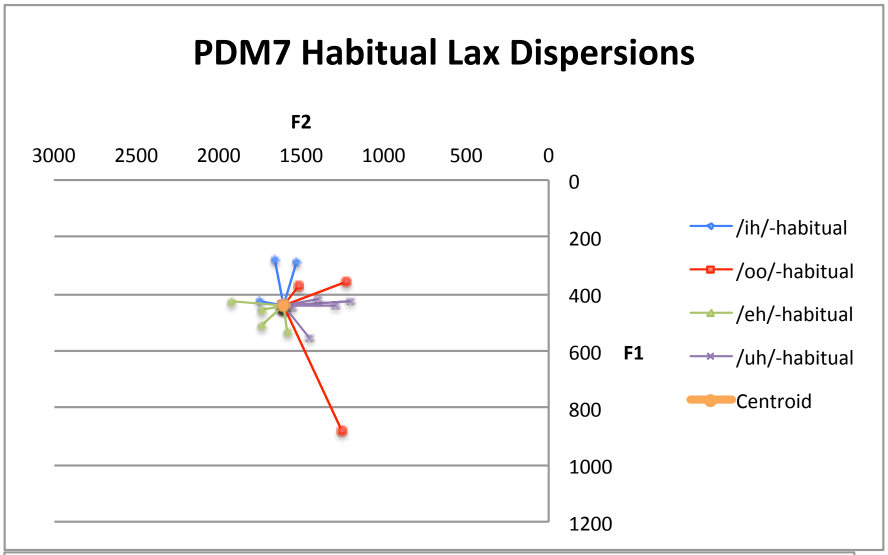
Parkinson's Male 7 Vowel Space Areas (Tense & Lax vowels) with combined Conditions (Habitual, Clear, Slow), and distances.

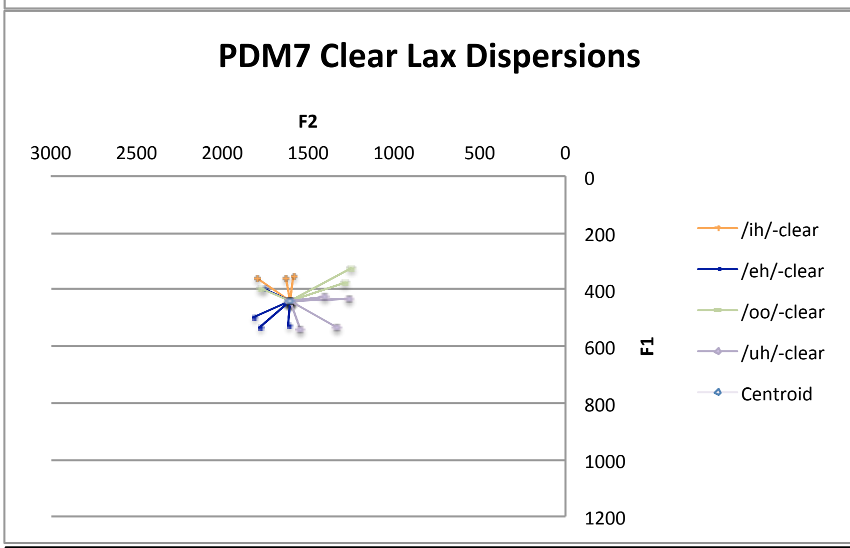


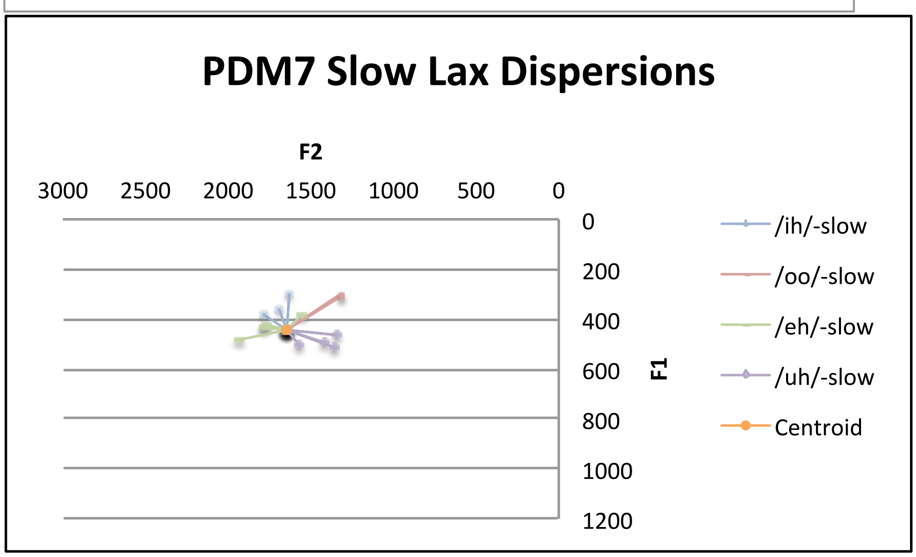




Parkinson's Male 7 Tense Vowel Dispersions for each Condition (Habitual, Clear, Slow).







Parkinson's Male 7 Lax Vowel Dispersions for each Condition (Habitual, Clear, Slow)

Bibliography

Anderson, D.M., Keith, J., Novak, P.D., and Elliot, M.A. (2002). *Mosby's medical, nursing, and allied health dictionary (6th ed.).* St. Louis, MS: Mosby, Inc.

Bjarnason, E.S., (2008). The effects of deep brain stimulation on the speech of patients with Parkinson's disease. *Masters Thesis.* Brigham Young University, Provo Utah

Bradlow, A.R. (2002). Confluent talker-and listener-oriented forces in clear speech production. *Laboratory Phonology, 7*, 241-273.

Bradlow, A.R., and Bent, T. (2002). The clear speech effect for non-native listeners. *Journal of the Acoustical Society of America, 112,* 272-284.

Bradlow, A.R., Torretta, G.M., & Pisoni, D.B. (1996). Intelligibility of normal speech I: Global and fine-grained acoustic-phonetic talker characteristics. *Speech Communication, 20,* 255-272.

Caligiuri, P.M. (1987). Labial kinematics during speech in patients with Parkinson rigidity. *Brain, 110,* 1033-1044.

Canter, G. (1965). Speech characteristics of patients with Parkinson's disease; III. Articulation, diadochokinesis, and overall speech adequacy. *Journal of Speech and Hearing Disorder, 30,* 217- 224.

Crystal, T. H., & House, A.S. (1982). Segmental durations in connected speech signals: Preliminary results. *Journal of the Acoustical Society ofAmerica,72,* 705-716.

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

Duffy, J.R. (1995). *Motor Speech Disorders: substrates, differential diagnosis, and management.* St. Louis: MO, Mosby.

Ferguson, S.H. (2004). Talker differences in clear and conversational speech: Vowel intelligibility for normal-hearing listeners[a)]. *Journal of the Acoustical Society of America, 116,* 2365-2373.

Ferguson, S.H., & Kewley-Port, D. (2002). Vowel intelligibility in clear and conversational speech for normal-hearing and hearing-impaired listeners. *Journal of the Acoustical Society of America, 112,* 259-271.

Ferguson, S.H., & Kewley-Port, D. (2007). Talker differences in clear and conversational speech: Acoustic characteristics of vowels. *Journal of Speech, Language, and Hearing Research, 50,* 1241-1255.

Flege, J.E. (1988). Effects of speaking rate on tongue position and velocity of movement in vowel production. *Journal of the Acoustical Society of America, 88,* 901-916.

Folstein, M., Folstein, S.E., & McHugh,P.R., (1975). "Mini-Mental State" a practical guide for grading the cognitive state of patients for the clinicians. *Journal of Psychiatric Research, 12(3),* 189- 198.

Forrest, K., Weismer, G., & Turner, G.S. (1989). Kinematic, acoustic, and perceptual analyses of connected speech by Parkinsonian and normal geriatric adults. *Journal of the Acoustical Society of America, 85(6),* 2608-2622.

Fox, C.M, Morrison, C.E., Ramig, L.O., & Sapir, S. (2002). Current perspectives on the Lee Silverman voice treatment (LSVT) for individuals with idiopathic Parkinson's disease. *American Journal of Speech-Language Pathology, 11,* 111-123

Goberman, A.M. & Elmer, L.W. (2005). Acoustic analysis of clear versus conversational speech in individuals with Parkinson disease. *Journal of Communication Disorders, 38,* 215-230.

Hammen, V.L., & Yorkston, K.M. (1996). Speech and pause characteristics following speech rate reduction in hypokinetic dysarthria. *Journal of Communication Disorders, 29,* 429-445.

Kjellson,L., Norrby,L., van Doorn, J. (2008). Effects of Subthalamic Nucleus Stimulation on Vowel Space in Parkinson's Disease. *Masters Thesis, UMEA Universitet in Sweden*.

Kleinlow, J., Smith, A. & Ramig, L.O. (2001). Speech motor stability in IPD: Effects of rate and loudness manipulations. *Journal of Speech, Language, and Hearing Research, 44,* 1041-1051.

Krause, J.C., & Braida, L.D. (2002). Investigating alternate forms of clear speech: The effects of speaking rate and speaking mode on intelligibility. *Journal of the Acoustical Society of America, 112,* 2165-2172.

Krause, J.C., & Braida, L.D. (2004). Acoustic properties of naturally produced clear speech at normal speaking rates. *Journal of the Acoustical Society of America, 115,* 362-378.

Krause, J.C., & Braida, L.D. (2009). Evaluating the role of spectral and envelope characteristics in the intelligibility advantage of clear speech. *Journal of the Acoustical Society of America, 125,* 3346-3357.

Ladefoged (2001). *A course in phonetics 4th ed.* Orlando: Harcourt Brace.

McRae, P.A., Tjaden, K. & Schoonings, B. (2002). Acoustic and perceptual consequences of articulatory rate change in Parkinson disease. *Journal of Speech, Language, and Hearing Research, 45*, 35-50.

Neel, A. (2008). Vowel space characteristics and vowel identification accuracy. *Journal of Speech, Language, and Hearing Research, 51,* 574-585.

Parkinson's Action Network, 2011
http://www.parkinsonsaction.org/parkinsons-disease/parkinsons-disease

Peterson, G. E. & Barney, H. (1952). Control methods used in the study of vowels. *Journal of the Acoustical Society of America, 24,* 175-184.

Picheny, M.A., Durlach, N.I. & Braida, L.D. (1986). Speaking clearly for the hard of hearing II: Acoustic characteristics of clear and conversational speech. *Journal of Speech and Hearing Research, 29,* 434-446.

Pickett, J.M. (1999). *The Acoustics of Speech Communication Fundamentals, Speech Perception Theory, and Technology.* Needham Heights, MA: Allyn & Bacon

Ramig, L.O., Countryman, S., Thompson, L.L., & Horii, Y. (1995). Comparison of two form of intensive speech treatment for Parkinson's disease. *Journal of Speech and Hearing Research, 38,* 1232-1251.

Raphael, L.J., Borden, G.J., & Harris, K.S. (2007). *Speech Science Primer Physiology, Acoustics, and Perception of Speech 5th ed.* Baltimore: MD, Lippincott Williams & Wilkins.

Sapir, S., Ramig, L.O., & Fox, C. (2006) The Lee Silverman Voice Treatment for voice, speech and other orofacial disorders in patients with Parkinson's disease. *Future Neurology, 1,* 563-570.

Sapir, S., Spielman, J.L., Ramig, L.O., Story, B.H. & Fox, C. (2007). Effects of intensive voice treatment (the Lee Silverman voice treatment [LSVT]) on vowel articulation in dysarthric individuals with idiopathic Parkinson disease: Acoustic and perceptual findings. *Journal of Speech, Language, and Hearing Research, 50,* 899-912.

Smiljanic, R., and Bradlow, A. R. (2005). Production and perception of clear speech in Croatian and English. *Journal of the Acoustical Society of America, 118*, 1677-1688

Smiljanic, R., and Bradlow, A. R. (2008a). Stability of temporal contrasts across speaking styles in English and Croatian. *Journal of Phonetics 36,* 91-113.

Smiljanic, R., and Bradlow, A. R. (2008b). Temporal organization of English clear and conversational speech [a)]. *Journal of the Acoustical Society of America, 124,* 3171-3182.

Smiljanic, R., and Bradlow, A. R. (2009). Speaking and hearing clearly: Talker and listener factors in speaking style changes. *Language and Linguistics Compass, 3,* 236-264.

Solomon, N.P., Lorell, D.M., Robin, D.A., Rodnitzky, R.L. and Luschei, E.S. (1995). Tongue strength and endurance in mild to moderate Parkinson's disease, *Journal of Medical Speech-Language Pathology, 3,* 15-26.

Solomon, P.N, Robin, D.A. and Luschei, E. (2000). Strength, endurance, and stability of the tongue and hand in Parkinson's disease. *Journal of Speech, Language, and Hearing Research, 43,* 256-267.

Stevens, K (1989). On the quantal nature of speech. *Journal of Phonetics, 17*, 3-45

Tjaden, K (2000). A preliminary study of factors influencing perception of articulatory rate in Parkinson disease. *Journal of Speech, Language, and Hearing Research, 43,* 997-1010.

Tjaden, K., Rivera, D., Wilding, G. & Turner, G.S. (2005). Characteristics of the lax vowel space in Dysarthria. *Journal of Speech, Language, and Hearing Research, 48,* 554-566.

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.

Turner, G.S., Tjaden, K. & Weismer, G. (1995). The influence of speaking rate on vowel space and speech intelligibility for individuals with Amyotrophic Lateral Sclerosis, *Journal of Speech, Language, and Hearing Research, 38,* 1001-1013.

Uchanski, R. M. (2005). Clear Speech, In D.B. Pisoni & R.E. Remez (Eds.), *Handbook of Speech Perception,* Blackwell Publishers, Malden, MA, p. 207-235.

Verbaan, D., Marinus, J., Visser, M., van Rooden, S.M., Stiggelbout, A.M., Middelkoop, H. A. M., van Hilten, J.J. (2007). Cognitive impairment in Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry with Practical Neurology. 78,* 1182-1187.

Wang, E., Metman, L. V., Bakay, R., Arzbaecher, J., & Bernard, B. (2003). The effect of unilateral electrostimulation of the subthalamic nucleus on respiratory/phonatory subsystems of speech production in Parkinson's disease, a preliminary report. Clinical Linguistics & Phonetics, 17, 283-289.

Weismer, G., Jeng, J-Y, Laures, J.S., Kent, R.D. & Kent, J.F. (2001). Acoustic and intelligibility characteristics of sentence production in neurogenic speech disorders. *Folia Phoniatrica et Logopaedica, 53,* 1-18.

Weismer, G., and Laures, J.S. (2002). Direct magnitude estimates of speech intelligibility in Dysarthria: Effects of a chosen standard. *Journal of Speech, Language, and Hearing Research, 45,* 421-433.

Weismer, G., Laures, J.S., Jeng, J-Y., Kent, D. & Kent, J.F. (2000). Effects of speaking rate manipulations on acoustic and perceptual aspects of the dysarthria in Amyotrophic Lateral Sclerosis. *Folia Phoniatrica et Logopaedica, 52, 201-219.*

Weismer, G., Yunusova, Y. & Westbury, J.R. (2003). Interarticulator coordination in dysarthria: An x-ray microbeam study. *Journal of Speech, Language, and Hearing Research, 46,* 1247-1261.

Whalen, D. H., Magen, H. S., Pouplier, M., Kang, A. M., & Iskarous, K. (2004). Vowel production and perception: Hyperarticulation without a hyperspace effect. Language and Speech, 47, 155-174.

Yunusova, Y., Weismer, G., Westbury, J.R., & Lindstrom, M.J. (2008). Articulatory movements during vowels in speakers with dysarthria and healthy controls. *Journal of Speech, Language, and Hearing Research, 51,* 596-611.