The Role of Stress in the Differential Diagnosis of Apraxia of Speech and Aphasia

Jennifer G. Ferranti
University of Central Florida

THE ROLE OF STRESS IN THE DIFFERENTIAL DIAGNOSIS OF APRAXIA OF SPEECH AND APHASIA

by

JENNIFER FERRANTI

A thesis submitted in partial fulfillment of the requirements
for the Honors in the Major Program in Communication Sciences and Disorders
in the College of Health and Public Affairs
and in the Burnett Honors College
at the University of Central Florida
Orlando, Florida
Summer Term, 2018
Thesis Chair: Joshua Troche, Ph. D

ABSTRACT

The intent of this thesis is to explore the factors of differential diagnosis between apraxia of speech (AOS) and aphasia, specifically using vowel length to determine Pairwise Variability Index (PVI) of productions. AOS has many common characteristics with its clinical neighbors, aphasia and dysarthria, and they often co-occur. This causes accurate differential diagnosis using symptoms and characteristics to be difficult. The aim of this study was to continue research based on previous data (Bislick, et. al., 2017) and develop the quantification of AOS features, particularly the deficits of prosodic elements, lexical stress and duration. This study investigated whether PVI can be used as sensitive tool for the differential diagnosis of AOS. Specifically, we sought to determine whether analysis of vowel length of stressed and unstressed syllables is helpful in differentiating between individuals with AOS and aphasia versus aphasia alone.

The results from this research showed a significant difference that supports the hypothesis that PVI, analyzed from vowel length, is uniquely affected in AOS. With the information given, a replication study would be helpful to confirm the theory, but is necessary to implement this in a clinical setting. Our results show a significant difference, so the next step is to discover the most effective and realistic way for Speech-Language Pathologists to apply this information into clinical cases for differential diagnosis.

DEDICATION

For my Nana, who always believed in me and inspired me to follow all my dreams.
Mary Ballou Gray, Ph. D., 1935-2018

A special thanks to Mom, Dad and Todd whose love and support has been essential to my every accomplishment.

ACKNOWLEDGEMENTS

There are many people who I must acknowledge for the success of this thesis. First, Dr. Troche, my Thesis Chair, thank you for allowing me to work alongside you and providing me this amazing opportunity where I discovered a true love for research.

I would also like to thank Dr. Bislick-Wilson, our Committee Member who provided the data and from her clients for this research and for her encouragement and help throughout the process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUPPLEMENTAL MATERIALS

PRAAT Program Instructions

To analyze an audio file in PRAAT, the file must be saved as .mp3, .aiff, or .wav. Open the PRAAT program and two windows will appear. The only one you will need is the PRAAT Objects window, so you may close the other window, PRAAT Pictures. On the Objects window, select “open,” and from the drop-down options, choose “read from file.” This allows you to search your computer for the file you wish to analyze. Select the audio file and click “view and edit.” The top layer of the new window shows the waveform of the audio recording and the bottom layer shows the spectrogram.

To view more details of the speech sample, like pitch, select “pitch” in the top bar, then “show pitch.” You can view intensity by clicking it in the top bar, then “show intensity.” The graph will pop up over the window to show these values. Total duration is shown when you click the bar below the transcription labeled accordingly. You can click and drag on the sample to view the duration of a section of speech. To playback the entire sample, click the total duration bar. To playback a section, click the corresponding time bar.

You can also create sections by using boundaries in the sample. To do this, click on the speech sample. A boundary line appears with a circle at the top. Click the circle to set this boundary. To get more precise boundaries, you can zoom into your selection by clicking “sel” in the bottom left corner. You can click and drag to create a new selection or zoom in and out with

the other options in the bottom left of the page. These allow you to see both layers of a section in more detail.

If you wish to save the changes made to the graph, go back to the PRAAT Objects window and select “Textgrid sample.” Choose “save as a short text file.” The file can be opened later with the Text Editor application. The format of the saved file will show the start and end time of the whole sample, starting with 0. The number of segments is shown beneath that. The following lines include the start and end time for each segment. The durations can be confirmed by comparing them to the times shown on the PRAAT window.

CHAPTER ONE: APRAXIA OF SPEECH

Acquired apraxia of speech (AOS) is a motor speech disorder that usually results from damage to the left hemisphere, particularly the areas of the brain that facilitate speech production (Duffy, 2013; McNeil et al., 2009). Individuals with AOS experience a disruption in the process of motor planning/programming of purposeful movements required for speech (Mailend, 2013). While AOS is a motor speech disorder, it is not an impairment at the level of the muscles (Jacks, 2013). Rather, the disorder results from impairment of the translation of intact phonological information into a code readable by the motor system (McNiel et al., 2009), often leading to impaired articulation and prosody (Duffy, 2013). Simply, the neural commands for articulator movement are unclear or impaired, whereas the other stages of speech production are intact. The AOS profile has overlap with both dysarthria and aphasia leading to difficulties in the differential diagnosis of the disease. There are, however, some unique characteristics of the AOS profile that may aid in their differential diagnosis. One area of uniqueness is in the realm of prosody and stress. This study attempts to characterize these stress impairments while also exploring their value for differential diagnosis.

Previous research was considered in the preparation of the current study, especially conclusions from research by both Vergis and Ballard (Vergis, M. K., Ballard, K. J., Duffy, J. R., McNeil, M. R., Scholl, D., & Layfield, C., 2014; Ballard, J. K., Azizi, L., Duffy, J. R., McNeil, M. R., Halaki, M., O'Dwyer, N., Robin, D. A., 2016). Both of these studies, as well as the current study, used Pairwise Variability Index (PVI) to measure lexical stress. Vergis' experimentation of lexical stress for differential diagnosis of AOS and aphasia provided results that strong syllables are usually longer in duration, greater intensity, and have a higher

fundamental frequency, however, duration seems to be the best cue according the previous studies (Vergis et al., 2014). Other information considered from Vergis' research included that this stress deficit was more apparent in the case of initial weak syllable that precedes a stressed syllable. Ballard also found significance for PVI in the initial weak presentation, with the addition that increasing word length was also significant to PVI scores. The current study included data analysis of both initial weak and initial strong presentations, as well as multiple syllable length words (two-, three-, and five-syllables) in exploration of the previous conclusions of PVI. The current study found no significant effect of word length or stress location on PVI, but confirmed the significance of PVI as a reliable metric for differential diagnosis of AOS and aphasia.

Characteristics of AOS

AOS is a disruption in the ability to plan/program the spatial and temporal movements for fluid speech production (Duffy, 2013; McNeil et al., 2009; van der Merwe, 1997). AOS typically results from left hemisphere cerebral vascular damage, especially near Pars Triangularis and Broca's area (Duffy, 1995; Duffy, 2013). The impact AOS can have on communication can range in severity from minimal disruption to an inability to produce speech entirely (Duffy, et al., 2013). The speech of persons with AOS is characterized by sound distortions, distorted substitutions, prolonged phonemes, slowed rate, impaired stress, and abnormal prosody (McNeil et al., 2009; Wambaugh et al., 2006). With regard to the articulatory characteristics, persons with AOS often demonstrate difficulty with word initial sounds, higher frequency of errors in nonsense words compared to meaningful words, and increased errors on words of increasing length (Duffy, et al., 2013). Consonant clusters are more difficult than their singleton counterparts in AOS, but there is still a higher error frequency in consonants compared to

vowels. Purposeful speech often contains more errors than repetition likely due to the more complex task of interpreting and creating an independent response in a real-life conversation. Perceived substitutions, particularly substitutions involving place and manner is also a common error patterns identified in AOS. However, the perceived substitutions are actually distortions so extreme, that they cross the phonemic boundaries and sound like a different phoneme (Duffy, et al., 2013). Pitch and intensity require careful control for natural-sounding and fluid speech. These prosodic elements are often impaired in individuals with AOS. The failure to apply these and other prosodic elements, like lexical stress, in speech accurately can cause speech to become unintelligible. Impaired lexical stress, accentuation of individual words, can also alter the meaning of a word and/or important connotative cues. Impaired prosody and lexical stress are known to be a main characteristic of AOS.

Etiologies

There are a variety of etiologies for AOS, but most clinical cases are the result of stroke (Cherney, 2009), though recent work has noted that some degenerative diseases may also cause AOS (Roth, 2006). AOS has also been associated with TBI and brain tumors. Orofacial apraxia, while a common comorbid disease with AOS, does not always occur if someone has AOS (Roth, 2006). It has been suggested that these findings indicate there are different motor programming systems for orofacial movement and speech movement.

Lesions within the left, language-dominant hemisphere are the primary neurological cause for this disorder, most often areas of the brain near Pars Triangularis and Broca's area. Damage to this brain area seems to cause the motor planning/programming deficits seen in AOS (Duffy, 1995). However, because AOS typically occurs with other disorders like aphasia and dysarthria, researchers have found it difficult to identify a specific location associated with pure AOS

(Moser, 2016). In addition, lesions that damage a large area or multiple areas of the brain present more obstacles in determining the location of damage that causes AOS (Moser, et al., 2016). Some studies have found areas of the brain that may be linked to the different causes of AOS. For example, one study built on previous research and found that stroke-induced AOS was associated with the left motor areas, while challenging the theory that damage to the left anterior insula is required or sufficient to cause AOS (Moser, et al.,2016). Overall, it was proposed that damage to the motor system in the brain is the root cause of AOS although there remains controversy as to the exact location of the dysfunction.

While there remains some controversy as to the exact mechanism of dysfunction in AOS, most agree that AOS causes an incompetence in motor planning/programming, the motor plans and programs for the placement of the articulators may be incorrect and result in inaccurate productions. Although an individual may be able to construct words and sentences with linguistic/phonemic neural accuracy, if there is damage to speech motor planning/programming the linguistic information may not be communicated accurately. To better understand AOS, it is important to view the disorder through the lens of speech production. One framework which has been influential to our understanding of AOS is the Van der Merwe framework which we discuss below.

Van der Merwe's Framework of Speech Production

One model used in research of disordered speech production, Van der Merwe's Four Level of Framework of Speech Production (van der Merwe, 2009) provides a well-rounded and well supported concept. The model combines data obtained from brain imaging as well as measurable observations of behavioral outcomes for each level of speech. The Van der Merwe model allows for a thorough description of speech disorders by differentiating the stages of

normal speech production and how they may be affected by damage. Typically, damage to any of the levels leads to communication deficits. According to the model, damage to each level of speech production leads to different deficits and disorders, and determining the location of damage can provide valuable information for both diagnosis and treatment of speech disorders.

The first of the four levels of the neural speech pathway is linguistic-symbolic planning. This level begins at the construction of the thought and deals with the phoneme selection and sequencing required to linguistically represent the idea. This initial stage of speech production also includes the understand and application of semantics, morphology, phonology during the organization and planning of the phonemes. The temporal-parietal areas of the brain are active during this stage. Broca's and Wernicke's Aphasia are classified as a disorder in linguistic-symbolic planning level of speech production.

The second stage of Van der Merwe's Framework of Speech Production where AOS is classified is the motor planning level. This level is involved in motor planning of said phonemes from the first level and begins the transformation of abstract linguistic plans into a code that is readable by the motor speech system in the brain. During the motor planning stage, the speech sound qualities of place of articulation, manner of production, voicing, and timing are determined for each phoneme. Pathologies in this level are not related to muscle tone or capacity, rather a disconnect in the connection between linguistic symbols and the instructional information required to physically produce speech. In other words, an individual with a motor planning level pathology may be able to construct an idea and select the correct sounds to produce the intended words, but the motor goals required to produce the sounds are inaccessible. The inability to control speech sound qualities causes the perceived incorrect stress and prosody in individuals with AOS. It is important to note that this stage adapts motor production to

context, like applying coarticulation of adjacent phonemes as needed for fluent speech. This also contributes to the prosodic deficits seen in disorders of this level.

Motor programming is the third level of Van der Merwe's model. This idea of motor planning as a completely separate level of speech production from motor programming is somewhat new but well-supported by the framework and provides further differentiation of disorders with similar perceived characteristics. This is where the motor plans from the previous level are equated to specific muscle movement commands. The muscle tone, movement, velocity, direction, force, and range of motion are included in the programming code. According to Van der Merwe's research, the basal ganglia and lateral cerebellum are the locations of the motor programming level. Damage at the motor programming stage of speech production can result in speech deficits associated with Parkinson's disease and cerebellar disease.

The final stage that results in speech is execution. At this level, the plans and programs identified in the previous levels are applied to create the actual movements for the speech sounds. In one review of the van der Merwe model, it is noted that this fourth and final level activates many different areas of the brain, particularly the motor cortex, lower motor neurons, peripheral nerves, and motor units within the muscles (Bislick, et al., 2017). However, similarly to previous levels, execution causes activity in the supplementary motor area, cerebellum, and basal ganglia.

Differential Diagnosis

AOS in isolation is rare and is often accompanied by aphasia and/or dysarthria (i.e., unilateral upper motor neuron dysarthria). It is therefore necessary to define the characteristics and symptoms of aphasia and dysarthria to assist with differential diagnosis.

Aphasia is defined as a disruption to the initial stage of speech communication, phonological structure and rules of linguistic messages (Cherney, 2009; van der Merwe, 2009). Substitutions are common, typically of one phoneme or syllable for another (Cherney, 2009). This substitution is present during both production and perception, since individuals with aphasia replace syllables when they produce and hear speech, and often misinterpret the meaning of what they hear (Cherney, 2009). One characteristic of AOS that is not expected in aphasia is frequent sound distortions and distorted sound substitutions. On the other hand, comprehension difficulties are common in aphasia, but not present in individuals with pure AOS. For these differences, there are many similarities of AOS and aphasia including a slow rate of speech, variation of repeated attempts of a word and perceived substitutions. However, true substitutions are seen in aphasia and not AOS. Because both disorders have overlapping symptoms and result in similar impairments of speech, the unique features must be studied in depth to support accurate differential diagnosis.

Dysarthria is a collective term for a group of speech disorders that cause disturbances to any of subsystems involved speech production, including impairment at the level of respiration, phonation, articulation, resonance, and prosody (Cherney, 2009; Duffy, 2013). The clinical diagnostic features of dysarthria include the neuromuscular tests of muscle strength, speed, range, accuracy, steadiness, and tone (Cherney, 2009). Dysarthria differs from AOS in that individuals with AOS do not present any muscle weakness related to the disorder. Dysarthria is also distinguishable from AOS based on symptoms and error patterns. Many of the defining features of AOS are not associated with dysarthria, including distorted sound substitutions or additions, trial and error groping, and increased difficulty for more complex utterances with increased length and rate (Josephs et al., 2012). Some of the features that are found in dysarthria

but not AOS are strained voice quality, reduced volume of speech, hypernasality, or accelerated speech rate (Josephs et al., 2012).

The overlapping profiles of AOS, aphasia, and dysarthria create difficulties for the process of differential diagnosis. The unique prosody and stress deficits, however, seen in AOS may aid in the diagnosis of the disease. It is first important, however, to determine the role of prosody and stress in normal speech processing.

CHAPTER TWO: PROSODY

Stress and Prosody in Speech

Stress and prosody are vital to competent communication skills. Lexical stress is defined as the accentuation of stressed syllables in words. Prosody encompasses elements like lexical stress, intensity, frequency, and duration that help speech sound fluid and natural. Prosody, along with lexical stress, contributes to linguistic functions such as intonation, tone, stress, and rhythm and is vital to competent verbal communication. Stress is quantified by intensity, vowel length, and frequency shifts. Syllables serve as the divider between different parts of a word, as well as clues to the meaning of the word within the context of a sentence. When stress is employed in different parts of a word, it can change the meaning, such as in the word 'present'. When produced with initial stress, the word can be utilized as an adjective or noun, depending on the context. When produced with final stress, it represents a verb with multiple interpretations. The many elements of prosody may seem similar in some ways, but each feature, lexical stress, intonation, and duration of stressed syllables, contribute to speech intelligibility in different ways (Field, 2005).

Purpose of Lexical Stress and Prosody in Communication

Competent prosody, demonstrated by the accurate use of stress across a phrase or sentence, is necessary to accomplish speech intelligibility. Certain words are stressed in a sentence, while others are unstressed, for the purpose of fluid and effective communication. Typically, important or key words in a sentence may be stressed through greater intensity or duration. Frequency is particularly important at the end of the sentence to indicate punctuation, as in the rising frequency associated with a question or falling frequency at the end of a statement. Prosody and lexical stress also serve to divide extended, complicated chunks of speech into smaller sections, like phrases and words (Field, 2005). Using prosodic cues like

accentuated stress on certain syllables and words, the listener can easily distinguish the start and end of words and sections of speech. Lexical stress can be broken down into strong (S) or weak (W) patterns. Strong syllables are usually longer in duration, have greater intensity, and have a higher fundamental frequency. Words like 'paper' represent a SW pattern, the most predominant stress pattern for multisyllabic words in English, while 'refer' follows a WS pattern. In addition, nouns are typically associated with a SW pattern while verbs usually follow a WS pattern, although there are exceptions for both.

Another important role of prosody in speech is to convey the emotion of the speaker. There is evidence that listeners can accurately recognize the speaker's emotion related to the utterance based on prosodic cues such as relative change in pitch, loudness, timing, and voice quality (Coutinho, 2013). These features of speech have the ability to give additional information about the speaker's attitude towards the topic of discussion (Pell, 2011). Manipulating the prosodic features provides emotional implications conveyed by the speaker and is an important part of effective communication.

Prosodic Deficits

Deficits that affect stress and prosody can severely impact the clarity and intelligibility of one's speech. If incorrect stress is applied to a word, it may cause speech to sound unnatural to the listener. Consequently, the purpose of the speech production may be overlooked or unclear. Further, inaccurate lexical stress can cause some words to be lost in connected speech (Field, 2005). Stress patterns also help listeners determine the boundaries of words within a phrase or sentence. Without lexical stress cues, syllables of a word may sound disconnected and lose their meaning. Clearly, prosodic deficits can affect the clarity of a phrase or sentence as a connected unit. In disorders that are associated with prosodic deficits, the flow of connected speech often

abnormal due to inaccurate accentuation. Previous studies have concluded that shifting stress, regardless of vowel quality, impairs intelligibility of speech (Field, 2005). Producing words with improper lexical stress can even cause perception of a different word with similar stress properties. For example, producing the word 'follow' incorrectly with final syllable stress, "fol-LOW'" may be perceived as "below" because of the inaccurate stress pattern.

Prosodic deficits can occur in many different disorders. Although it is a primary feature of AOS, prosodic impairments are present in many individuals with language-related disorders like Parkinson's Disease and Alzheimer's Disease. Incidents such as TBI or stoke can also deteriorate prosodic competence, especially when Broca's area is damaged, due to its important role in producing speech from motor neural signals. The multitude of disorders that can cause prosodic deficits is evidence that further research must be done in understand and treat them better.

Abnormal prosody in AOS is characterized by slow speech rate, prolonged phonemes, syllable segmentation, prosodic deficits including lexical stress. As previously stated, lexical stress is defined as the accentuation strong syllables in a word. The ability to use stress in speech is essential to convey the intended content (Cutler, 1997). Lexical stress is associated with the features of fundamental frequency, intensity, and duration. Prosodic deficits may include a reduction of intensity from syllable to syllable within words and phrases, and excessive stress on unstressed syllables, making them less distinguishable from stressed syllables in speech. These characteristics and others, like increased frequency and duration of pauses between syllables and slower overall rate of speech, can severely impair an individual's intelligibility. Interestingly, although abnormal prosody and stress are hallmark characteristics of AOS there is limited research in this area, especially the development of treatments protocols that target these areas

(e.g., Ballard et al., 2015). Thus, further research in AOS and its etiologies, manifestation, and unique defining characteristics is necessary to improve management of this disease. Obtaining specific data on how stress and prosody are impaired in AOS may aid in both the differential diagnosis of the disorder and the management of these deficits.

Dysprosody is a common feature of AOS, and on a phonetic level is perceived as incorrect stress of words. The perception of stress is affected by duration of syllable production, a characteristic of AOS, particularly in the case of vowels in the initial weak position that precedes a stressed syllable (Vergis, 2014). The perception of dysprosody in AOS is often due to their tendency to equalize stress between weak and strong syllables, as opposed to a lack of stress on the strong syllable (Vergis, 2014). Vowel duration alone was proven to be highly correlated with the perceptual judgement of overall prosodic competence, as well as the main cause of slow rate of speech and restricted pitch range (Boutsen, 2017). In relation to pitch range, individuals with AOS have a flatter relative peak intensity across contrastive weak and strong syllable which causes strong and weak syllables to be more difficult to distinguish, contributing to the perception of inappropriate stress.

Syllable segregation is another prosodic deficit that is present in AOS. Syllable segregation is the insertion of brief pauses between syllables (Vergis, 2014). These pauses may be so significant that the syllables are perceived as separate words. In addition to duration and pitch, syllable segregation contributes to the unnatural flow of speech that is common of individuals with AOS. The wide range of impairments that occur in AOS, including inaccurate lexical stress, syllable segregation, inconsistent articulation and sequencing errors, also affect the ability to add connotative or emotional ties to language. These various stress and prosody related deficits have severe impacts on speech intelligibility, fluidity, and prosodic cues of emotion for

individuals with AOS. They are, therefore, important to understand for the purposes of management but as stated above there is also the possibility of leveraging these deficits to aid in differential diagnosis.

Methods of Analysis of Stress and Prosody

Lexical stress and prosody are often quantified by fundamental frequency, duration, intensity, and spectral characteristics. Fundamental frequency is measured in Hertz (Hz), or cycles per second throughout the sentence, as well as frequency shifts on stressed syllables or words. Duration is typically measured in time units including seconds and milliseconds. Intensity is quantified by the sound pressure level (SPL), and results are evaluated in decibels (dB). Finally, spectral characteristics used in speech analysis include measures of energy distribution at different ranges of audible frequency. PVI, as explained above, is also a helpful measure in defining the deficits in stress. This measure allows the clinician to determine if the individual is placing equal stress across syllables or possible excess stress across syllables.

While the above objective measures are common in research of stress and prosody, clinical work often measures prosody and stress subjectively. Clinicians often make determinations about deficits in prosody and stress based on their judgement of the naturalness of the speech.

PVI calculates the difference in either duration, intensity or fundamental frequency of two adjacent syllables then divides the difference by the average of the two measurements. As noted before, high PVI values indicate greater contrast while lower values indicate little difference between the two syllables and thus display equal stress. In AOS there is less variation between stressed and unstressed syllables, resulting in a value close to zero. Vergis focused on the first two syllables of each word in both an isolated and sentence condition. They found that

vowel prolongation was present in both conditions, although more pronounced in a sentence condition. The current study expanded the data analysis to include two-, three-, and five-syllable words, which similarly proved to have no significant effect on the PVI analysis. Similar conditions were used in this study, with the modification of sentence condition to blocked, where the participants repeated the word five times consecutively. However, the data analysis only included the first repetition of both blocked and random conditions.

CHAPTER THREE: PURPOSE OF CURRENT STUDY

AOS is a disorder related to motor planning and programming of speech production. Like many other language disorders, it usually results from left hemisphere damage. AOS has many other similarities to other speech and language disorders, like common symptoms and characteristics. Differential diagnosis for AOS uses information from observations of symptoms, many of which are common in other speech and language disorders. The aim of this retrospective study, based on data from Bislick, McNeil, Spencer, Yorkston, & Kendall, 2017, was to investigate whether PVI can be used as sensitive tool for the differential diagnosis of AOS. This study evaluated the PVI values for individuals with aphasia alone and aphasia with AOS and analyzed the data in search of distinct differences between the disorders. Individuals with AOS were expected to have less variation between stressed and unstressed syllables, resulting in a low PVI value.

CHAPTER FOUR: METHODS

Overview

The participants in this study were chosen based on specific inclusion and exclusion criteria, unanimous diagnosis agreement among three experienced speech language pathologists, and were evaluated by formal tests for diagnosing speech disorders. The 21 participants were seated in a quiet room and given instructions to repeat the words they hear. Stimuli included two-, three-, and five-syllable words, divided into two lists, A and B. High quality video and audio recordings were used to document the experiment. The current study is a reanalysis of data using the PVI method

Participants

The participants in this study include ten individuals with acquired AOS and aphasia and eleven individuals with aphasia only, labeled Group A and P respectively. Group A participants range from 45-71 years of age among four men and six women, while group P consists of five men and six women ranging from 49-91 years of age. Both groups of participants were at least six months post-onset of the diagnosis. The inclusion criteria were right-handedness, English as L1 (primary language), minimum high-school education, passed hearing tests for at least one ear, vision competence, and a score above a 23/36 on the Raven's Coloured Progressive Matrices. Individuals were excluded if they had a history of psychiatric, degenerative neurological or chronic medical illnesses, or presence of dysarthria.

Participants with AOS were chosen based on observational diagnosis by three certified speech-language pathologists with at least 20 years of experience and proficiency in differential diagnosis, ensuring 100% diagnostic agreement. The evaluation included performance on multiple subsets of Apraxia Battery for Adults-Second Edition, as well as professional

observation of picture description tasks and the Story Retell Procedure (SRP). The defining features of AOS used for selecting participants was slow speech rate, sound, syllable, or word segregation, distortions and substitutions, and prosodic abnormalities. Participants with aphasia were more accurately attained using the Comprehensive Aphasia Test and the Standardized Assessment of Phonology in Aphasia. Finally, a level of severity of speech impairment was designated to each participant on a scale from 1-3 to reflect mild, moderate, severe impairment.

Materials & Procedure

The stimuli for this experiment were specifically chosen with the intent to induce errors in individuals with AOS. The stimuli included two-, three-, and five-syllable words that are motorically complex with consonant clusters. Two lists of 15 words was initially created: List A and List B. Both lists were matched ($p<.05$) on the following psycholinguistic variables: frequency of use, age of acquisition, imageability, concreteness, familiarity, neighborhood density and phonetic probability. Part of speech, number of phonemes and clusters, articulatory features (voice, place, manner) and overall structure were also in agreement between the words of List A and B. The words were categorized as either initial WS or initial SW (refer to Table 1). Between both lists, there was a total of 19 SW words and 11 WS words. In the SW group, there were 9 two-syllable, 5 three-syllable, and 5 five-syllable words. For WS, there was 1 two-syllable word, 5 three-syllable words, and 5 five-syllable words. A native English-speaking adult man was selected to act as the model for stimulus elicitation. The production of each stimuli was re-recorded until determined 100% accurate by three members of the University of Washington Aphasia Research Laboratory. For this study, of the 30 words presented to the participants, two were removed from the analysis in this study: ‘electricity’ and ‘preference.’ Productions were

varied across subjects of both diagnoses, and some produced ‘preference’ as a two-syllable words while others used three syllables, a difference unrelated to diagnosis.

Table 1: Stimuli by WS/SW and Syllable Length

Presentation	Total	Two-syllable	Three-syllable	Five-syllable
WS	11	1	5	5
SW	19	9	5	5

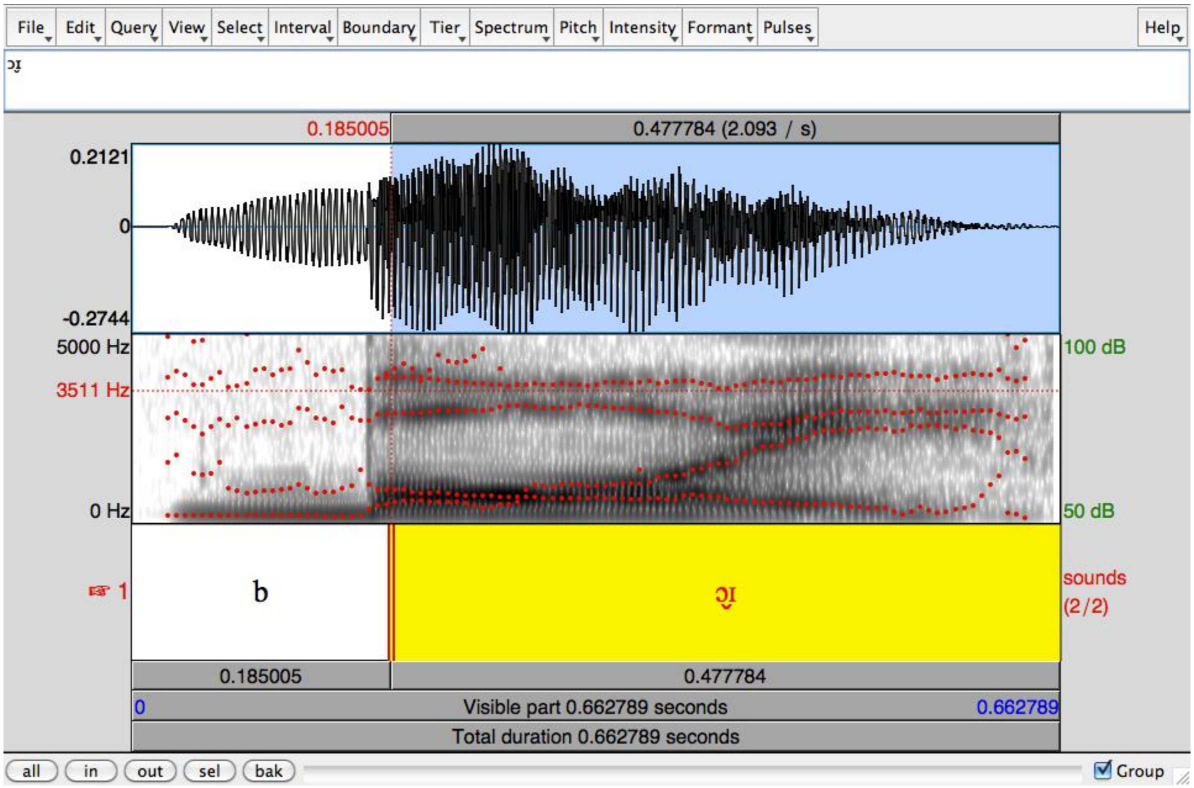
The experimental procedure began by seating the participants in a designated quiet room at the University of Washington Aphasia Research Laboratory or at the participant’s home. Stimuli for the testing was presented through loudspeakers and video recording of the articulators was presented on a monitor. Participants were directed to watch and listen to the target word. If the word was from List A, the blocked condition, participants would then repeat it five times as quickly and clearly as possible. If the word was from List B, the random condition, then participants were asked to repeat the word once and would then be presented with the next word on the list.

Data Analysis

The data from this study was analyzed using the Pairwise Variability Index (PVI), which, as explained above, calculates the difference in duration, intensity or fundamental frequency of two adjacent syllables then divides the difference by their average. The PVI was extracted through manual dissection of each word in order to isolate the syllable in question using PRAAT. PRAAT is a program that shows the spectrogram and waveforms of an audio recording. Speech

can be analyzed in detail by zooming into a selection of speech. PRAAT can show the length, intensity and frequency shifts of a selected speech sample. For this study, the length of vowels was found using zoom and boundary features. The vowels in the speech sample are represented by the dark sections of the spectrogram, but specific boundaries were extracted manually (refer to Figure 1). Using the dark bands as a guide, the vowel was centered and the selection was zoomed in with two clicks, and the boundary for the vowel was set. To confirm accuracy, each boundary was zoomed in a third click and edited to more precisely include only the vowel and no surrounding consonants. Many of the words were produced with coarticulation of vowels and surrounding consonants, which made the boundaries of the vowel more difficult to perceive. The dark bands in the spectrogram were heavily relied on to determine the onset and offset of the vowel in coarticulated productions. Detailed instructions for this experiment's process using PRAAT are located in supplemental materials. After the measurements of the syllables were attained, the difference between the two measurements was calculated as well as the average of the two measurements.

Figure 1: PRAAT Spectrogram Example



Note: Spectrogram of the word "boy" analyzed by a linguistics researcher from University of Münster.

A linear mixed effects model was conducted to examine the effect of diagnosis on PVI. We were also interested in determining if word length (i.e., 2,3,5 syllable), stress order (i.e., WS, SW), and presentation type (i.e., Blocked, Random) had an effect on PVI. Data was analyzed using the lme4 package (Bates & Sarkar, 2006) in the R environment (R Core Team, 2017). The fixed effects for the model were diagnosis, word length, stress order, and presentation type. The random effects for the model were participant and item, in other words, we wanted to see if our model improved by including random intercepts for participant (n=21) and word (n=28).

CHAPTER FIVE: RESULTS

Linear Mixed Effect Model

A Linear Mixed Effect Models was performed for the outcome measure. Models were built up first with fixed effects, then by adding random effects, and finally interactions. The improvement in fit was determined using chi-square tests on the log-likelihood values.

The best fit model included fixed effects of diagnosis, as well as the random effects of participant and word. No other fixed effects or interactions improved the fit of the model. There were significant fixed effects of diagnosis [$t(18.42)=-4.275$, $p<.05$]. Analysis of the means for the two groups revealed that individuals with AOS had significantly shorter PVI scores compared to individuals with Aphasia (See Table 2).

Table 2: AOS and PP Responses

				95% CI	
Participant	Complete Productions	Mean	SD	LB	UB
AOS 1	27	30.65531808	22.57486987	21.65531808	39.58563918
AOS 2	28	28.69857472	22.58080841	19.9426513	37.45449815
AOS 3	24	45.31944052	36.28487487	29.99768162	60.64119942
AOS 4	28	44.35935621	38.76539591	29.32770491	59.39100752
AOS 5	28	35.10085809	22.11098086	26.52711476	43.67460141
AOS 6	28	32.66491741	21.78421428	24.21788094	41.11195388
AOS 7	27	40.97454092	31.08401866	28.67811268	53.27096917
AOS 8	28	39.86773056	37.42678804	25.355137	54.38032392
AOS 9	28	37.75650625	31.52530904	25.53226755	49.98074495
AOS 10	27	26.6404908	21.51794607	18.12827484	35.15270676
PP 1	28	53.79008077	39.11495752	38.62288362	68.95727792
PP 2	27	58.77916957	39.92740423	42.9844145	74.57392464
PP 3	27	51.61163453	32.55828159	38.7320073	64.49126177
PP 4	28	45.57991092	30.16446504	33.88335243	57.2764694
PP 5	28	47.16419646	27.31869938	36.5711107	57.75728221
PP 6	21	43.57482257	27.25422395	31.16884857	55.98079658
PP 7	28	47.98057387	32.33521332	35.44228708	60.51886066
PP 8	28	47.1092372	35.60024907	33.30490172	60.91357269
PP 9	26	36.53948192	21.38090388	27.90354795	45.17541589
PP 10	28	47.19139087	28.70325129	36.06143193	58.32134981
PP 11	24	44.13401781	34.36944857	29.6210725	58.6469311

Note: SD=standard deviation, CI=confidence interval, LB=lower boundary, UB=upper boundary, AOS=apraxia of speech, PP=Aphasia

Table 3: Average PVI by Diagnosis

Diagnosis	PVI	SE	df	Lower CI	Upper CI
AOS	36.34	3.08	33.74	30.07	42.61
PP	47.71	3.04	33.50	41.53	53.89

Note: SE=standard error, df=degrees of freedom, CI=confidence interval, AOS=apraxia of speech, PP=Aphasia

CHAPTER SIX: DISCUSSION

The results from the current study showed a significant difference between PVI for participant groups of AOS and aphasia and those with only aphasia. These findings suggest that differences exist in terms of the use of stress across these diagnoses and also indicate that PVI may be useful in the future as a diagnostic measure. In this study, lexical stress was quantified by measuring vowel length and applying the PVI formula.

The results of this study help broaden our understanding of AOS and its effect on lexical stress. A better understanding of these disorders allows, not only for improved differential diagnosis, but also for better targeting of these stress deficits in treatment. Having a well-founded understanding of AOS brings the opportunity to discover the most direct therapy that tackles the stress deficits in AOS that cause speech to be perceived as impaired. In addition, because this study proved the deficit of increased vowel duration affects measured PVI, perhaps studies can be done that use this deficit to discover more effective methods of treatment. Research on treatment of stress deficits in AOS is neglected compared to other targeted symptoms, such as syllable structure and word length (Aichert, et al., 2018). One study explored the effect of Sound Production Treatment (SPT) on patients with AOS, which provides steps to treatment using modeling, repetition, contrastive practice, orthographic cueing, integral stimulation, and articulatory cueing (Wambaugh, et al., 2018). The study concluded that replication studies are necessary to determine the effect of this treatment on other characteristics of AOS. Data from PVI analysis may lead to further understanding on how the current treatments affect the unique stress deficits seen in AOS.

With the information from the current data analysis, there is support to suggest that AOS can be differentiated as a group from aphasia accurately and reliably by using the PVI. The unique aspect of this newfound significance of stress in AOS provides the possibility for a consistent and measurable method of diagnosing AOS, even when it co-occurs with other disorders. Thus, the differential diagnosis of AOS can have the metric boundaries of PVI that may be able to diagnose the disorder with greater accuracy and with consistency among clinicians. Having a quantitative measurement, in addition to the trained clinicians' perceptions of speech deficits, combines to create a well-rounded, reliable method of diagnosis, as compared to the current method which relies heavily on qualitative analysis of speech.

This study was an extension of previous work; however, new and significant data was extracted from the methods of the current study. For example, this study analyzed productions of two-, three-, and five-syllable words, in both the weak-strong and strong-weak presentations. In previous work, only three syllable words were analyzed and significant differences were only seen in WS stress patterns. In this study, we found significant differences across stress patterns and syllable lengths.

With data that supports PVI as a valid tool for group different diagnosis of AOS and aphasia, clinical application is the next step of research in this area. For example, how can this method be used by a clinician to diagnose a patient in a hospital, private practice, or home? Can a program be designed like PRAAT that analyzes PVI of a patient's productions in some way that is easy and quick for the clinician, or even automated? These and many other research questions can be extracted from the results of the current study. Further, the current study only found significance for group differences but provides the information to explore individual

differences in detail. Impaired ability to accurately apply lexical stress is unique in AOS, but is also a characteristic of other speech disorders. Therefore, the information from the current study may be used to aid in diagnosis and/or treatment of other disorders that cause stress deficits, like Parkinson's Disease. Hopefully, with continued research on implementation of the measurable characteristic of PVI, the results from this study may both aid in more accurate differential diagnosis as well as treatment of AOS and comorbid or similar speech-language disorders.

Study Limitations and Future Recommendations

Although the participants covered a range of degree of impairment, similar to that seen in a clinical setting, a larger sample size would likely yield stronger support for the current results. It should also be noted that a small number of productions from the 21 participants were too inaccurate to analyze for certain words and conditions, and were therefore not included in the data. In addition, the imbalance of WS and SW words from the current study may be considered in future research, by altering or increasing the word list to confirm that stress pattern does not have a significant effect on PVI in differential diagnosis.

The current study was successful in researching group data, but did not go in detail into individual data. Vergis noted this group focus in her study as well, while Ballard was able to extend the procedure to include each individual analysis to determine diagnosis and severity (Vergis et al., 2014; Ballard, et al., 2016). The individual variability in the results of the current study can be seen more clearly in Table 4, which shows the two groups separately organized from lowest to highest mean. Between participants AOS 4 and PP 11 there is overlap of scores between AOS and PP. Further research into the individual differences within these groups, as well as the overlap of mean scores between about 40-45. The current study did not account for

individual differences that would affect the range of scores but it does provide a foundation for future studies.

Table 4: Individual Differences and Group Overlap

				95% CI	
Participant	Complete Productions	Mean	SD	LB	UB
AOS 10	27	26.6404908	21.51794607	18.12827484	35.15270676
AOS 2	28	28.69857472	22.58080841	19.9426513	37.45449815
AOS 1	27	30.65531808	22.57486987	21.65531808	39.58563918
AOS 6	28	32.66491741	21.78421428	24.21788094	41.11195388
AOS 5	28	35.10085809	22.11098086	26.52711476	43.67460141
AOS 9	28	37.75650625	31.52530904	25.53226755	49.98074495
AOS 8	28	39.86773056	37.42678804	25.355137	54.38032392
AOS 7	27	40.97454092	31.08401866	28.67811268	53.27096917
AOS 4	28	44.35935621	38.76539591	29.32770491	59.39100752
AOS 3	24	45.31944052	36.28487487	29.99768162	60.64119942
PP 9	26	36.53948192	21.38090388	27.90354795	45.17541589
PP 6	21	43.57482257	27.25422395	31.16884857	55.98079658
PP 11	24	44.13401781	34.36944857	29.6210725	58.6469311
PP 4	28	45.57991092	30.16446504	33.88335243	57.2764694
PP 8	28	47.1092372	35.60024907	33.30490172	60.91357269
PP 5	28	47.16419646	27.31869938	36.5711107	57.75728221
PP 10	28	47.19139087	28.70325129	36.06143193	58.32134981
PP 7	28	47.98057387	32.33521332	35.44228708	60.51886066
PP 3	27	51.61163453	32.55828159	38.7320073	64.49126177
PP 1	28	53.79008077	39.11495752	38.62288362	68.95727792
PP 2	27	58.77916957	39.92740423	42.9844145	74.57392464

Note: SD=standard deviation, CI=confidence interval, LB=lower boundary, UB=upper boundary, AOS=apraxia of speech, PP=Aphasia

Finally, the overarching goal recommended for future research is finding methods of clinical application of PVI in differential diagnosis. This study provided significant data that supports the role of lexical stress in the accurate differential diagnosis of AOS and aphasia. This information must be implemented in a way that is accessible to a clinician in a more efficient way. While it is possible to replicate the methods of this study to aid in differential diagnosis, it is too time-consuming and therefore unrealistic for clinical application. Research is necessary to discover the most efficient application of the current supported results to aid clinicians in differential diagnosis and possibly treatment of aphasia and AOS. It is also important to note that differences seen in the following study were group differences so it remains unclear how this would be applied on an individual basis. Future work in this area should focus on standardized PVI scores. This would require gathering PVI scores on a set words produced by healthy controls. With a standardization of PVI scores, boundaries may be found for what exact scores reflect different disorders and what would be considered the PVI score necessary to diagnose someone with AOS.

REFERENCES

Aichert, I., Spaeth, M., & Ziegler, W. (2018). The role of metrical information in apraxia of speech. Perceptual and acoustic analyses of word stress. *Neuropsychologia*, *82*171-178.

Ballard, J. K., Azizi, L., Duffy, J. R., McNeil, M. R., Halaki, M., O'Dwyer, N., . . . Robin, D. A. (2016). A Predictive Model for Diagnosing Stroke-Related Apraxia of Speech. *Neuropsychologia, 81*, 129-139.

Basilakos, A., Yourganov, G., Ouden, D.-B. d., Fogerty, D., Rorden, C., Feenaughty, L., & Fridriksson, J. (2017). A Multivariate Analytic Approach to the Differential Diagnosis of Apraxia of Speech. *Journal Of Speech, Language & Hearing Research, 60*(12), 3378-3392.

Bates, D., & Sarkar, D. (2006). The lme4 Package. Retrieved from https://cran.r-project.org/web/packages/lme4/

Bislick, L., McNeil, M., Spencer, K. A., Yorkston, K., & Kendall, D. L. (2017). The Nature of Error Consistency in Individuals With Acquired Apraxia of Speech. *American Journal of Speech-Language Pathology, 26*(2S), 611-630.

Boutsen, F., & Dvorak, J. (2017). Prosody and Motor Speech Disorders: A Retrospective Review of a Merger That Is Imminent. *Lingua: International Review Of General Linguistics, 199*, 50-59.

Cherney, L. R., & Small, S. L. . (2009). *Aphasia, Apraxia of Speech, and Dysarthria*.

Coutinho, E., & Dibben, N. (2013). Psychoacoustic cues to emotion in speech prosody and music. *Cognition & Emotion, 27*(4), 658-684.

Cutler, A., Dahan, D., & van Donselaar, W. (1997). Prosody in the Comprehension of Spoken Language: A Literature Review. *Language & Speech, 40*(2), 141-201.

Dabul, B. L. (2000). Apraxia Battery for Adults, Second Edition.

Deger, K., & Ziegler, W. (2002). Speech motor programming in apraxia of speech. *Journal Of Phonetics, 30*(3), 321-335.

Duffy, J. R. (1995). *Motor Speech Disorders: Substrates, Differential Diagnosis, and Management*. Montana: Mosby.

Duffy, J. R. (2013). *Motor speech disorders : substrates, differential diagnosis, and management*. St. Louis, MO : Elsevier Mosby, [2012] c2013.

Field, J. (2005). Intelligibility and the Listener: The Role of Lexical Stress. *TESOL Quarterly, 39*(3), 399-423.

Haley, K. K., Jacks, A., de Riesthal, M., Abou-Khalol, R., Roth, H. L., Smith, A., & Ziegler, W. (2012). Toward a quantitative Basis for Assessment and Diagnosis of Apraxia of Speech. *Journal Of Speech, Language & Hearing Research, 55*(5).

Jacks, A., & Robin, D. A. (2013). *Apraxia of speech.*: Wiley-Blackwell.

Josephs, K. A., Duffy, J. R., Strand, E. A., Machulda, M. M., Senjem, M. L., Master, A. V., . . . Whitwell, J. L. (2012). Characterizing a neurodegerative syndrome: primary progressive apraxia of speech. *Brain: A Journal of Neurology, 135*, 1522-1536.

Keith, R. L., & Aronson, A. E. (1975). Singing as therapy for apraxia of speech and aphasia: report of a case. *Brain and Language, 2*, 483-488.

Kent, R. D., & Rosenbek, J. C. (1983). Acoustic Patterns of Apraxia of Speech. *Journal of Speech, Language, and Hearing Research, 26*, 231-249.

L. (2011, March 11). Praat: Diphthongs. Retrieved from https://lisaloveslinguistics.wordpress.com/2011/03/10/praat-diphthongs/

Maas, E., Robin, D., Wright, D., & Ballard, K. (2008). Motor programming in apraxia of speech. *Brain & Language, 106*(2), 107-118.

Mailend, M. m., & Maas, E. (2013). Speech Motor Programming in Apraxia of Speech: Evidence From a Delayed Picture-Word Interference Task. *American Journal of Speech-Language Pathology, 22*(2), S380-S396.

Mauszycki, S. C., Wambaugh, J. L., & Cameron, R. M. (2012). Apraxia of Speech: Perceptual Analysis of Trisyllabic Word Productions Across Repeated Sampling Occasions. *American Journal of Speech-Language Pathology*, S28-37.

Moser, D., Basilakos, A., Fillmore, P., & Fridriksson, J. (2016). Brain damage associated with apraxia of speech: evidence from case studies. *Neurocase*, *22*(4), 346-356.

Nooteboom, S. (1997). The Prosody of Speech: Melody and Rhythm. *The Handbook of Phonetic Sciences, 5*.

Pell, M. D., Jaywant, A., Monetta, L., & Kotz, S. A. (2011). Emotional speech processing: Disentangling the effects of prosody and semantic cues. *Cognition & Emotion, 25*(5), 834-853.

R Core Team. (2017). R: A Language and Environment for Statistical Computing: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org

Roth, H., Eskin, T., Kendall, D., & Heilman, K. (2006). Progressive Oculo-Orofacial-Speech Apraxia (POOSA). *Neurocase (Psychology Press), 12*(4), 221-227.

Santen, J. P. H. v., Prud'hommeaux, E. T., & Black, L. M. (2009). Automated Assessment of Prosody Production. *Speech Communication, 51*(11), 1082-1097.

Strand, E. A., Duffy, J. R., Clark, H. M., & Josephs, K. (2014). The Apraxia of Speech Rating Scale: A Tool for Diagnosis and Description of Apraxia of Speech. *Journal Of Communication Disorders, 51*, 43-50.

Van der Merwe, A. (1997). A theoretical framework for the characterization of pathological speech sensorimotor control. In: M.R. McNeil, (Editor), Clinical Management of Sensorimotor Speech Disorders. New York: Thieme Medical Publishers.

Van der Merwe, A. (2009). A theoretical framework for the characterization of pathological speech sensorimotor control. In: M.R. McNeil, (Editor), 2nd Edition, Clinical Management of Sensorimotor Speech Disorders. New York: Thieme Medical Publishers.

Van Lieshout, P., Bose, A., Square, P., & Steele, C. (2007). Speech motor control in fluent and dysfluent speech production of an individual with apraxia of speech and Broca's aphasia. *Clinical Linguistics & Phonetics*, *21*(3), 159-188.

Van Putten, S. M., & Walker, J. P. (2003). The Production of Emotional Prosody in Varying Degrees of Severity of Apraxia of Speech. *Journal Of Communication Disorders*, *36*(1), 77-95.

Vergis, M. K., Ballard, K. J., Duffy, J. R., McNeil, M. R., Scholl, D., & Layfield, C. (2014). An acoustic measure of lexical stress differentiates aphasia and aphasia plus apraxia of speech after stroke. *Aphasiology*, *28*(5), 554-575.

Wambaugh, J. L., Nessler, C., Cameron, R., & Mauszycki, S. C. (2012). Acquired Apraxia of Speech: The Effects of Repeated Practice and Rate/Rhythm Control Treatments on Sound Production Accuracy. *American Journal of Speech-Language Pathology*, S5-S27.

Wambaugh, J. L., Wright, S., Boss, E., Mauszycki, S. C., DeLong, C., Hula, W., & Doyle, P. J. (2018). Effects of Treatment Intensity on Outcomes in Acquired Apraxia of Speech. *American Journal Of Speech-Language Pathology*, *27*306-322.

Ziegler, W., Aichert, I., Staiger, A., Smith, A., & Liss, J. (2012). Apraxia of Speech: Concepts and Controversies. *Journal Of Speech, Language & Hearing Research, 55*(5), 1485-1501.