ABSTRACT

Title of thesis: CONNECTED LANGUAGE IN PRIMARY PROGRESSIVE
APHASIA: TESTING THE UTILITY OF LINGUISTIC
MEASURES IN DIFFERENTIALLY DIAGNOSING PPA AND
ITS VARIANTS

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Difficulty in using language is the primary impairment in Primary Progressive Aphasia (PPA). Individuals with different variants of PPA have been shown to have unequal deficits in various domains of language; however, little research has focused on finding common deficits in PPA that could aid in the differential diagnosis of PPA relative to healthy aging and age-related neurogenerative conditions. The commonality of deficits in variants of PPA was explored in this study by examining the connected speech of 26 individuals with PPA (10 with PPA-G, 9 with PPA-L, 7 with PPA-S), compared to 25 neurologically healthy controls, 20 individuals with Mild Cognitive Impairments (MCI), and 20 individuals with Alzheimer's Dementia (AD). Measures of fluency, word retrieval, and syntax were used to assess linguistic ability in a between-groups comparison, in addition to a within-groups comparison of the same linguistic measures among specific PPA variants. It was found that participants with PPA showed significant deficits on certain measures of fluency, word retrieval, and syntax. These findings support the idea that a brief language sample has clinical utility in contributing to the differential diagnosis of PPA.

CONNECTED LANGUAGE IN PRIMARY PROGRESSIVE APHASIA: TESTING
THE UTILITY OF LINGUISTIC MEASURES IN DIFFERENTIALLY DIAGNOSING
PPA AND ITS VARIANTS

by

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Master of Arts
2017

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Introduction

Primary Progressive Aphasia (PPA) is a language impairment caused by neurodegenerative disease (Mesulam, 1982, 2001, 2003, 2007; Mesulam, Wieneke, Thompson, Rogalski, & Weintraub, 2012). It is primarily marked by a gradual decline in language production, object naming, syntax, or word comprehension abilities that is apparent through conversation or speech and language assessments (Gorno-Tempini et al., 2011). The three core criteria for diagnosing PPA are: a language disorder that is not caused by motor or perceptual deficits, that the language impairment is the most salient deficit affecting activities of daily living, and that the underlying disease pathology is progressive in nature (Mesulam, 1982, 2001, 2003, 2007; Mesulam et al., 2012). Exclusion criteria that must be answered negatively include: that the pattern of deficits is better accounted for by another medical disorder or psychiatric diagnosis, the presence of prominent deficits in memory or visuoperceptual skills, and the presence of prominent behavioral disturbances (Mesulam, 2001). Given that the only positive indicator of PPA, language decline affecting activities of daily living, is likely not evident until the disease has progressed significantly, early confirmatory diagnosis of PPA is still an under-developed science.

Cognitive abilities remain generally intact in the early years of PPA, hence commonly used measures that differentiate healthy aging individuals from those who have other neurodegenerative diseases such as Alzheimer's Dementia may not be sensitive to the diagnosis of PPA. For example, according to the criteria on healthy aging established by Tyas and colleagues (2007) it would be expected for a healthy aging individual to obtain a score of 24 or above on the Mini Mental State Exam (MMSE;

Folstein, Folstein, & McHugh, 1975), which is a measure of cognitive impairment that is scored out of 30 possible points. However, even approximately four years past the initial diagnosis of PPA, studies have reported that participants obtained scores on the MMSE that were within normal limits (Ash et al., 2006; Bird, Lambdon-Ralph, Patterson, & Hodges, 2000; Fraser et al., 2014; Mack et al., 2015; Meteyard & Patterson, 2009; Wilson et al., 2010). Thus, for the early differential diagnosis of PPA, cognitive measures such as the MMSE are insufficient, although they may aid clinicians in ruling out cognitive impairments in patients.

To date, a small number of studies have analyzed connected speech samples in order to characterize the speech and language abilities of participants with PPA (Ash et al., 2013; Mack et al., 2015; Thompson et al., 2012; Wilson et al., 2010). There have also been methodological criticisms of some studies conducted, which have included small sample sizes (Bird et al., 2000; Kavé, Leonard, Cupit, & Rochon, 2007; Meteyard & Patterson, 2009) and unspecified coding methods (Ash et al., 2006; Graham, Patterson, & Hodges, 2004; Meteyard & Patterson, 2009). The purpose of the present study is to evaluate a semi-automated analysis protocol of connected language to differentially diagnose early PPA from healthy aging and other neurodegenerative conditions, and its subtypes. This method has the potential to be clinically useful in acting as a screening measure for PPA, as the linguistic content of narrative language samples provides a global understanding of a person's speech and language abilities.

Subtypes of PPA

Although a progressive disorder of language associated with frontal and temporal left hemisphere atrophy was first described in the 1890's (Pick, 1892; Serieux, 1893),

different terms have been used to describe PPA and its variants throughout the years. Over the last few decades, a distinction has been made between "semantic dementia" (Snowden, Goulding, & Neary, 1975) and "progressive non-fluent aphasia" in the literature (Grossman et al., 1996), where the former is linked to a fluent form of PPA, and the latter form refers to a non-fluent type of PPA.

Recent consensus criteria have identified 3 subtypes of PPA to account for a wider variety of clinical symptoms than were encompassed by the previously used binary diagnostic labels. The 3 subtypes of PPA currently used are *agrammatic* (PPA-G), *semantic* (PPA-S), and *logopenic* (PPA-L; Gorno-Tempini et al., 2011). When patients present with features characteristic of multiple PPA subtypes, they are classified as having a "mixed" PPA (Gorno-Tempini et al., 2011). As the PPA progresses, patients often develop "mixed" language symptoms. Therefore, the subtype of mixed PPA will not be discussed in this study, which is concerned with early differential diagnosis. Patients with PPA-G present with non-fluent speech and impaired syntax (Gorno-Tempini et al., 2011). Patients with PPA-S present with impaired semantics, with the core features of anomia and single-word comprehension deficits (Gorno-Tempini et al., 2011). Patients with PPA-L present with word retrieval difficulties, impaired repetition, and slowed speech with frequent pauses (Gorno-Tempini et al., 2011). PPA-L is a more recent diagnostic category, so it is possible that older studies included PPA-L participants in the "non-fluent" participant groups due to some of the speech disfluencies characteristic of the subtype.

Currently, there is little uniformity in measures that are used to quantify language abilities and impairments in PPA. Since many studies investigate select variants of PPA,

measures are often used to capture the specific deficits expected for the subtype. For example, semantic measures are used to quantify linguistic impairment in studies investigating semantic PPA (PPA-S), as semantic impairments are the most salient deficit in this subtype. However, in a subtype such as *agrammatic* PPA (PPA-G), where fluency and syntax are the main domains of language that are impaired, tests of semantic abilities may not be sensitive to the characteristics of PPA for these individuals. In summary, in order to attempt to quantify linguistic impairments in multiple domains (e.g., semantics and syntax), a test battery approach including a wide variety of standardized tests and language samples must be used. Depending on the measures used, different aspects of language impairment may be captured, yielding results that may not aid in the diagnosis of PPA.

In the following sections, previous research findings regarding language impairments in PPA compared to healthy aging are assessed in three categories: fluency, word retrieval, and syntax.

Language Production in Healthy Aging Compared to Primary Progressive Aphasia

PPA is a neurodegenerative disease in which clinical symptoms develop over the course of time, hence the early detection of PPA can be difficult due to the similarity of changes that occur in healthy aging individuals, especially when standardized tests are used. Given that language impairment is the primary indicator of early PPA, differences in the content of the language produced at the level of connected speech may be more clinically useful for diagnosing early PPA than tasks at the single word or sentence levels.

Unlike standardized testing, the analysis of language production can provide a more comprehensive picture of an individual's speech and language production abilities. For example, a commonly used standardized test that elicits language through confrontation naming is the Boston Naming Test (Kaplan, Goodlass, & Weintraub, 1983). This test informs to an individual's word retrieval abilities; however, assumptions regarding the individual's abilities in other domains of language, such as fluency and syntax, cannot be made based on this measure since it only elicits single words. Narrative language samples more domains of language than single tests or subtests of language. Additionally, language samples can provide a more ecologically valid view of how an individual speaks, as their performance on single word measures may dissociate from narrative speech.

Healthy aging

With regards to measures of fluency, it has been found that healthy adults have speech rates that remain similar to those of younger adults; however healthy aging adults may be slower to initiate speech when preparing simple labels in object naming tasks (Spieler & Griffin, 2006). Additionally, the speech of healthy aging adults is less efficient and contains more disfluencies (i.e., pauses, false starts, hesitations, and corrections) than that of younger adults, with disfluencies often preceding low encodable and low frequency word items (Bortfeld, Leon, Bloom, Schober, & Brennan, 2001; Spieler & Griffin, 2006). The disfluencies produced tend to coincide with the effects of language load, specifically when word selection requires selecting between multiple similar object names and when lower frequency words are used.

Although a decline in word retrieval abilities is often associated with aging, the slowed word retrieval that occurs in healthy aging is subtle, approximately 2% per decade, with most changes occurring after 70 years of age (Connor, Spiro, Obler, & Albert, 2004). Due to this slow rate of decline, it may take years before the decline in an individual's lexical-semantic retrieval abilities become measurable with standardized testing (Connor et al., 2004). It has also been found that healthy aging adults use more words to convey the same number of ideas as younger adults (i.e., lower idea density; Kemper, Greiner, Marquis, Prenovost, & Mitzner, 2001).

Additionally, a decline in the syntactic complexity of narratives occurs gradually across the lifespan of healthy aging adults (Kemper et al., 2001). The sentences produced are likely to have fewer clauses, and are less likely to use complex structure (e.g., passive or object relative sentences), although their utterances tend to remain grammatically correct. These changes have been correlated with changes in working memory (Kemper et al., 2001).

Comparison of healthy aging and PPA

Table 1 contains a summary of research findings regarding speech and language production in both healthy aging individuals, and individuals with PPA.

Table 1 – Language in Healthy Aging vs. PPA

Population	Fluency	Lexical-Semantics and Phonology	Syntax
Healthy Aging	Similar rates of speech to younger adults, slower speech onset (Spieler & Griffin, 2006) More disfluencies in older adults (Bortfeld et al., 2001; Spieler & Griffin, 2006)	Difficulties with low encodable and low frequency word items (Spieler & Griffin, 2006) Subtle decline in word retrieval abilities (Connor et al., 2004)	Gradual decline in syntactic complexity with age (Kemper et al., 2001)

Primary Progressive Aphasia (PPA)	Reduced rate of speech compared to controls for some subtypes (Ash et al., 2006, 2013; Fraser et al., 2014; Graham et al., 2004; Knibb et al., 2009; Mack et al., 2015; Sajjadi et al., 2012; Thompson et al., 2012; Wilson et al., 2010) Disfluencies increase with some subtypes (Ash et al., 2013; Mack et al., 2015; Wilson et al., 2010)	Difficulties with low frequency, less imageable words in some subtypes (Bird et al., 2000; Fraser et al., 2014; Wilson et al., 2010) Word retrieval impairments in some subtypes (Ash et al., 2006; Kavé et al., 2007; Mack et al., 2015; Meteyard & Patterson, 2009; Sajjadi et al., 2012; Thompson et al., 2012; Wilson et al., 2010) Speech sound errors increase with some subtypes (Ash et al., 2013)	Reduced syntactic complexity in some subtypes (Ash et al., 2013; Knibb et al., 2009; Thompson et al., 2012) Reduced MLU in some subtypes (Ash et al., 2006, 2013; Graham et al., 2004; Knibb et al., 2009; Mack et al., 2015; Sajjadi et al., 2012; Thompson et al, 2012; Wilson et al., 2010) Reduced percent of grammatically well-formed sentences (Ash et al., 2013; Knibb et al; Mack et al., 2015; Thompson et al., 2012)

Healthy aging individuals, as well as individuals with PPA, experience declines in fluency, difficulties with lower frequency and less imageable words, and decreased use of complex syntax (Ash et al., 2013; Bird et al., 2000; Fraser et al., 2014; Kemper et al., 2001; Knibb, Woollams, Hodges, & Patterson, 2009; Mack et al., 2015; Spieler & Griffin, 2006; Wilson et al., 2010). Hence, it is difficult to differentiate early PPA from healthy aging in adults. However, as shown in Table 1, some differences in the speech and language of individuals with PPA may aid in the early detection of specific subtypes of the disease, including a reduced rate of speech, word finding impairments, reduced mean length of utterance (MLU), and an increase in grammatical errors (Ash et al., 2006, 2013; Connor et al., 2004; Fraser et al., 2014; Graham et al., 2004; Kavé et al., 2007; Knibb et al., 2009; Mack et al., 2015; Meteyard & Patterson, 2009; Sajjadi, Patterson, Tomek, & Nestor, 2012; Spieler & Griffin, 2006; Thompson et al., 2012; Wilson et al., 2010). It should be noted that a key difference in the speech and language of individuals

with PPA is that they not only experience a decline in language abilities like those experienced by healthy aging adults (e.g., declines in fluency, difficulty producing low frequency words, decreased complexity of syntax), but they also show deviations in their speech and language production abilities. Language produced by individuals with PPA contains more errors in fluency (e.g., false starts, pauses), semantics (e.g., semantic paraphasias), phonology (e.g., phonemic paraphasias), and syntax (e.g., ungrammatical sentences).

Although these linguistic impairments are indicators that could potentially be used to differentially diagnose variants of PPA, further research is needed to compare these impairments across all variants of PPA in order to determine if any single linguistic measure or combination of measures can differentiate individuals with PPA from healthy aging adults, or adults with cognitive decline. Based on the measures of interest analyzed in previous studies, findings on fluency, word retrieval, and syntax will be discussed in relation to the differential diagnosis of PPA and its variants.

Fluency in PPA

Fluency refers to an individual's facility of speech and language performance; individuals who speak fluently produce speech that is unbroken and flowing. According to Clark (2002), fluent speech requires the synchronization of communication between the speaker and the listener. This involves the synchronization of voice and ear, so speakers make sure their listeners are ready to hear their vocalizations, diction and analysis, making sure the listener can analyze the presented words correctly before they move on, and meaning and understanding, getting their listener to understand what they are saying before they continue speaking. However, all individuals produce disfluencies

in speech as strategies to achieve this multi-level synchronization. Common disfluencies include fillers (e.g., interjections such as "um" or "uh"), prolonged syllables, non-reduced vowels, restoration of continuity, and many others (Clark, 2002). Most of these dysfluencies are conventional, such as "uh" and "um," which are used to signal delays to the listener when the speaker is unable to plan their speech within the time limits expected (Clark, 2002; Clark & Fox Tree, 2002) Therefore, fluency reflects the cumulative endpoint of speech and language production processes from language formulation to speech production. Some disfluencies are normal; however, a large quantity of normal-type disfluencies may reflect deficits in the production of speech and language.

In the PPA literature, studies that have investigated fluency have used the following measures: words per minute, fluency disruptions per 100 words, and number of errors in categories such as false starts, unfilled pauses, filled pauses, and repaired sequences (Ash et al., 2006; Ash et al., 2013; Bird et al., 2000; Fraser et al., 2014; Garrard & Forsyth, 2010; Graham et al., 2004; Knibb et al.; Mack et al., 2015; Sajjadi et al., 2012; Thompson et al., 2012; Wilson et al., 2010). The measure of speech rate in intended words per minute is the most frequently used measure of fluency used to aid in the classification of PPA subtypes because individuals with PPA-G present with non-fluent, effortful speech, which can be captured by a reduced rate of speech. A summary of the results of studies investigating fluency in PPA can be found in Table 2.

Table 2 – Findings on Rate of Speech and Disfluency in PPA

Study	Task	Agrammatic PPA (PPA-G)		Semantic PPA (PPA-S)		Logopenic PPA (PPA-L)		Controls
		n	Finding	*n*	Finding	*n*	Finding	*n*
Ash et al. (2006)	Picture description and Narration of wordless picture book	10	Lowest words per minute compared to all groups	13	Reduced words per minute compared to controls	0	N/A	10
Ash et al. (2013)	Picture description	15	Lowest words per minute compared to all groups	18	Reduced words per minute compared to controls	29	Reduced words per minute compared to controls; greatest false starts and hesitations compared to controls	12
Bird et al. (2000)	Picture description	0	N/A	3	Comparable words per minute to controls	0	N/A	20
Fraser et al. (2014)	Narration of wordless picture book	14	Lowest words per minute compared to all groups	10	Comparable words per minute to controls	0	N/A	16
Garrard & Forsyth (2010)	Picture description task	0	N/A	21	Comparable words per minute to controls	0	N/A	21
Graham et al. (2004)	Picture description task	14	Lowest words per minute	0	N/A	0	N/A	11
Knibb et al. (2009)	Semi-structured conversation	15	Low words per minute	0	N/A	0	N/A	15
Mack et al. (2015)	Narration of wordless picture book	12	Lowest words per minute compared to all groups	12	N/A	11	Higher rate of pauses prior to nouns compared to controls	12
Sajjadi et al. (2012)	Picture description and Interview	0	N/A	16	Reduced words per minute	0	N/A	30
Thompson et al. (2012)	Narration of wordless picture book	11	Lowest words per minute compared to all groups	6	Comparable words per minute to controls	20	Reduced words per minute compared to	13

							PPA-S and controls	
Wilson et al. (2010)	Picture description	14	Lowest words per minute and maximum speech rates compared to all groups	25	Reduced words per minute compared to controls	11	Reduced speech rate compared to PPA-S and controls; increase in repaired sequences	10

Out of the eleven studies that compared measures of fluency, only three studies compared the performance of individuals across all three variants of PPA (Ash et al., 2013; Thompson et al., 2012; Wilson et al., 2010). In these studies, participants with PPA-G consistently had the lowest rates of speech, measured in words per minute. Participants with PPA-L showed reduced rates of speech, in addition to a high number of false starts and repaired sequences compared to controls. A study by Mack et al. (2015) also reported that participants with PPA-L exhibited the most pauses out of any PPA subtype, although all participants with PPA produced more pauses than control participants. The participants in the PPA-L group were the only group that showed a word class effect in their distribution of pauses (Mack et al., 2015). Specifically, the individuals in the PPA-L group produced the most pauses prior to producing nouns, with effects persisting even after accounting for lexical frequency. This difference shows that participants with PPA-L may demonstrate a unique pattern of pauses during word-finding that resembles lemma level impairments. Therefore, this measure may be useful not only in identifying PPA in participants, but also in identifying participants with PPA-L from participants with other subtypes of PPA. It should also be noted that in older studies, the newer diagnostic label of the PPA-L subtype was likely grouped with participants with PPA-G, due to the presence of impaired fluency. Findings on individuals diagnosed with

PPA-S were variable, with some studies reporting a reduced rate of speech compared to control participants (Ash et al., 2006, 2013; Sajjadi et al., 2012; Wilson, 2010), and others reporting rates of speech comparable to controls (Bird et al., 2000; Fraser et al., 2014; Garrard & Forsyth, 2010; Thompson et al., 2012).

Although a reduced rate of speech is often used to categorize participants with PPA-G, studies often do not report or analyze the types of disfluencies present in their connected speech samples, or in the speech samples of participants with other PPA subtypes. Further research that could better capture specific types of disfluencies, such as unfilled pauses, filled pauses, word repetitions, phrase repetitions, and phrase revisions, may be beneficial in better understanding if aspects of fluency are impaired across all subtypes of PPA, potentially aiding in the differential diagnosis of PPA from healthy aging and other neurodegenerative conditions.

Word retrieval in PPA

In speech production, word retrieval is a complex process that relies on having intact semantic representations (i.e., lemmas), being able to access these semantic representations, retrieving the phonological forms of each word (i.e., lexemes), having intact post-lexical phonological abilities to determine the number of syllables and intonation of the target word, and being able to prepare the corresponding articulatory gestures (Butterworth, 1992; Levelt, 1999; Ferreira, 2010). Therefore, difficulties with word retrieval can occur at many levels in the process of selecting and producing a target word. At the level of connected speech, these errors can have cascading effects on an individual's ability to produce fluent and grammatically correct speech. For example, inaccessible verbs and verb arguments will impact an individual's ability to form

syntactically correct sentences. Inaccessible lexemes will impact an individual's ability to correctly articulate a target word.

 A summary of the findings on word retrieval impairments in the different variants of PPA can be found in Table 3. Findings regarding lexical-semantics and phonology have been grouped within the larger category of word retrieval since they are both associated with word retrieval difficulties; however, they will be discussed separately as they reflect breakdowns in different parts of the word retrieval process.

Table 3- Findings on Word Retrieval in PPA

Study	Task	Agrammatic PPA (PPA-G)		Semantic PPA (PPA-S)		Logopenic PPA (PPA-L)		Controls
		n	Finding	*n*	Finding	*n*	Finding	*n*
Ash et al. (2006)	Picture description and Narration of wordless picture book	10	Impaired word finding compared to controls	13	Impaired word finding compared to all groups	0	N/A	10
Ash et al. (2013)	Picture description	15	Greater amount of nouns per hundred words used than controls*; most speech-sound errors	18	Less nouns per 100 words compared to controls ; lowest percent open-class words	29	More nouns used than PPS-S group, but less used than PPA-G group*	12
Bird et al. (2000)	Picture description	0	N/A	3	Used more high frequency, less imageable words; decreased use of content words	0	N/A	20
Fraser et al. (2014)	Narration of wordless picture book	14	Used higher frequency words (verbs) than controls	10	Used the most high frequency, familiar words compared to controls	0	N/A	16
Garrard & Forsyth (2010)	Picture description	0	N/A	21	Lower noun: verb ratio and content: function word ratio than controls	0	N/A	21
Kavé et al. (2007)	Narration of wordless picture book	0	N/A	1	Reduced use of open class words, nouns, and verbs compared to controls	0	N/A	5

Mack et al. (2015)	Narration of wordless picture book	12	N/A	12	Impaired noun: verb and closed: open ratios compared to controls	11	Reduced total nouns produced compared to controls	12
Meteyard & Patterson (2009)	Interview	0	N/A	8	Use more light nouns and verbs than controls	0	N/A	8
Sajjadi et al. (2012)	Picture description and Interview	0	N/A	16	Mostly substitution errors; higher proportion of closed-class words; more circumlocutions than controls; phonological errors equal to controls	0	N/A	30
Thompson et al., (2012)	Narration of wordless picture book	11	N/A	6	Fewer open: closed words and fewer nouns than PPA-G and control groups	20	N/A	13
Wilson et al. (2010)	Picture description	14	N/A	25	Greater proportion of pronouns, verbs, and high-frequency nouns produced compared to controls	11	Greater proportion of pronouns than controls	10

*A nonsignificant trend finding.

Lexical-semantics

Deficits in retrieving the lemma, or the meaning, of words results from the degradation of certain concepts in the mental lexicon. Generally, it is easier for individuals to retrieve lemmas referring to animate entities rather than inanimate entities, concrete entities rather than abstract entities, and concepts with a smaller number of lemmas to choose from are easier to retrieve than concepts that have more competing

lemmas (Ferriera, 2010). Semantic impairments at the lemma level of word retrieval are associated with semantic primary progressive aphasia (PPA-S).

Lemma-level semantic abilities have been examined both in terms of the occurrence of words in specific grammatical categories as well as the variety of words used. A decrease in the diversity of words used, and in specific word types that are used (e.g., nouns, verbs, adjectives), represents a degradation of that concept or group of concepts in the mental lexicon. Measures used to quantify the former include counts of unique words throughout a narrative sample. And the distribution of various grammatical categories has been quantified with measures such as open: closed class ratios (i.e., number of adjectives and nouns produced, compared to the number of function words produced) and noun: verb ratios. If the use of function words is reduced, individuals will have high open: closed ratios (i.e., over 1). Additionally, if the use of verbs is reduced, the individual will have a high noun: verb ratio (i.e., over 1). High ratios are associated with class-specific lemma-deficits and agrammatism.

Four of the eleven studies in Table 3 compared word retrieval abilities across all subtypes of PPA (Ash et al., 2013; Mack et al., 2015; Thompson et al., 2012; Wilson et al., 2010). These studies found that overall, participants with PPA-S used the least amount of nouns and had impaired open: closed class word ratios. Additionally, the findings from these studies showed that individuals with PPA-L had noun deficits compared to control participants, although not as significant as the noun deficits seen in PPA-S groups, and that individuals with PPA-G had verb deficits.

In summary, although lemma-based word retrieval deficits such as noun deficits and decreased use of content words are most commonly reported in PPA-S, individuals

with PPA-L also experience word retrieval deficits (i.e., pauses prior to producing nouns). These effects persist even after accounting for lexical frequency, suggesting that these pauses may be related to lemma-based impairments for nouns (Mack et al., 2015). Additionally, individuals with PPA-G also appear to have lemma-based word retrieval difficulties, although their difficulties are specific to verbs.

It is still unclear if there is a single lexical-semantic measure that captures evidence of language decline across all three varieties of PPA. Given that some PPA variants show a deficit in nouns (PPA-S, PPA-L), while others a deficit in verbs (PPA-G), measures such as noun: verb ratio may be insufficient to identify PPA versus healthy aging. Measures that quantify semantic diversity that are not tied to specific word classes are probably more suitable. Measures such as Type-Token Ratio (TTR: Templin, 1957), have been used in aphasia research to quantify lexical diversity. TTR is defined as the number of different words in a language sample divided by the total number of words in a language sample. It has been suggested that TTR is affected by the sample length, as people may be more likely to repeat words in lengthier samples, thus decreasing their lexical diversity as measured by TTR (Fergadiotis, Wright, & West, 2013). The Moving-Average Type-Token Ration (MATTR; Covington & McFall, 2010) has been suggested as a measure of lexical diversity that is less likely to be influenced by sample length than TTR. This measure is based on a moving window that calculates the TTR values for each window of a fixed length throughout the sample. The final value is an average of the TTR's calculated per window throughout the sample (Covington & McFall, 2010). To our knowledge, this measure has not been used to quantify lexical diversity in PPA,

although it may be a useful measure in quantifying lemma-based word retrieval impairments in PPA.

In a study by Thorne & Faroqi-Shah (2016), a study that retrospectively analyzed semantic and syntactic measures in story narrations of persons with aphasia using CLAN programs (MacWhinney, 2000), idea density was proposed as a measure to quantify the semantic density of a narrative sample. Findings from the *Nun Study* suggest that it is possible to identify persons at risk for developing late-life cognitive impairments in early adulthood using idea density, a linguistic measure associated with general knowledge and vocabulary that is not dependent on word class (Riley, Snowdon, Desrosiers, & Markesbery, 2005). Idea density is defined as the number of ideas, as identified by propositions (e.g., non-noun entities), expressed per 10 words. Low idea density was found to be associated with later-life cognitive function, as well as with more severe cases of dementia (Riley et al., 2005).

Another type of semantic analysis that has been used to with success in the aphasia literature is Correct Information Unit (CIU) analysis (Nicholas & Brookshire, 1993). CIU analysis is a standardized, rule-based scoring system that measures the words in a sample that are intelligible in context, accurate in relation to the picture, and relevant to and informative about the topic (Nicholas & Brookshire, 1993). This measure, unlike idea density, captures if the words used by the participant are correct, given the context of the task. However, to our knowledge, idea density and CIU analysis (and other measures of lexical diversity that are not word-class specific) have not been used to quantify semantic impairments in PPA relative to healthy aging adults and adults with other related neurodegenerative diseases.

Phonology

While word retrieval deficits can result from a loss of conceptual knowledge, they can also result from lexeme-level impairments in which the concept for the word is accessed (i.e. the lemma), but the phonological form of the word is inefficiently or ineffectively retrieved. Lexeme level deficits are characterized by frequency effects (i.e., lexemes for more common words are retrieved more easily than for less common words; Bose & Buchanan, 2007; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997), word length effects (i.e., longer words are more difficult to produce; Martin, 2011), and speech containing non-words (e.g., phonemic paraphasias and neologisms; Bose & Buchanan, 2007; Dell et al., 1997).

Individuals with PPA-S have been found to use more high frequency nouns (Bird et al., 2000; Meteyard & Patterson, 2009) and pronouns than control participants (Kavé et al., 2007; Meteyard & Patterson, 2009; Wilson et al., 2010). In the longitudinal study by Bird et al. (2000), the researchers found that as the disease progressed, the narratives produced by people with PPA-S contained more high frequency, familiar words than controls, with impaired noun production occurring earlier than impaired verb production. This suggests that lexeme-level impairments, in addition to lemma-based impairments, are present in PPA-S. Individuals with PPA-L have been found to use more high frequency nouns than individuals with PPA-G; however, this difference did not reach statistical significance (Ash et al., 2013). In individuals with PPA-L, the pause rate prior to producing nouns persists when lexical frequency is accounted for, suggesting that their word retrieval difficulties may be linked to lemma impairments in noun retrieval (Mack et al., 2015). However, this subtype is also associated with speech-sound errors that are

suggestive of lexeme-level deficits (Gorno-Tempini et al., 2011). Further research is needed to better understand the nature of word retrieval impairments in PPA-L. Additionally, Fraser et al. (2014) found that individuals with PPA-G produced more high-frequency verbs than control participants, suggesting that they may also have lemma-level deficits in word retrieval that are specific to verbs.

While word frequency is a measure that has been used in the analysis of narratives produced by individuals with PPA, these deficits are word class specific depending on PPA variant and this measure has not achieved statistical significance across all PPA subtypes. Additionally, research has shown that healthy aging individuals also demonstrate difficulties with producing low encodable and low frequency word items as they age (Spieler & Griffin, 2006). Therefore, word retrieval abilities as measured by word frequency may be insufficient for differentiating individuals with PPA from individuals from healthy aging adults and adults with other neurodegenerative diseases. In addition to the measures of semantics proposed (i.e., the D measure and idea density), error coding for lemma and lexeme level errors may yield more information about the nature of the deficits in individuals with PPA, and better differentiate individuals with PPA from healthy aging individuals and individuals with neurodegenerative diseases, than measures currently used.

Error Analysis

Both individuals with PPA and healthy aging individuals experience declines in word retrieval abilities; however, deviation is associated with language impairments. Individuals with PPA present with a higher number of word substitutions, circumlocutions, and speech-sound errors than healthy aging adults (Ash et al., 2013;

Sajjadi et al., 2012). In semantic paraphasias, there is an unintended word for word substitution of a word that is semantically similar to the target word. This can represent an inability to access the lemma of a word, so another related (often a more general, phonologically, or categorically related) word is used in its place. Speech-sound errors such as phonemic paraphasias can indicate a lexeme-level impairment in which the individual has access to the meaning of the word (i.e., the lemma) and has some access to phonology, but cannot retrieve the full phonological word form. Generally, these errors contain extra sounds, sounds that have been transposed, or the incorrect amount of syllables. In a mixed error, there is both an unintended word substitution for a related word and a phonological error made within the word. This error type represents a more severe degradation of the semantic system, as both the lemma and lexeme levels of word retrieval are impaired. Neologisms or jargon (i.e., producing non-words) also reflect a severe impairment of phonology in which less than 2/3 of the target phonemes match the target word, but the word follows the phonological rules of a language. Quantifying these errors could provide a way to capture global language impairment at both the lemma and lexeme levels in word retrieval, without being dependent on word class. Additionally, an analysis of error types could provide a deeper understanding of the level of deficits present in each PPA variant.

Morpho-syntactic production in PPA

Deficits in syntax are associated with agrammatism. Agrammatism is characterized by verb deficits, the use of few grammatical morphemes (e.g., articles, pronouns, auxiliaries, inflections), the presence of grammatical morpheme errors (e.g., verb inflection errors), and an overall reduction in syntactic complexity (Marshall, 2011).

Measures that have been used to quantify syntactic impairments in PPA have focused on the length of utterances, grammatical complexity, and grammatical errors present in the utterances produced.

A measure commonly used to quantify the complexity of language in English is the mean length of utterance (MLU). MLU is calculated by adding the total number of morphemes in a sample and dividing it by the total number of utterances in the sample. This measure has traditionally been used to index children's speech and language development in a way that is more reliable than using their ages, with higher MLU values indicating more language proficiency (Brown, 1973). In adults, this is a global measure that has been used to capture the complexity of syntax in narrative language, with higher MLUs generally reflecting the use of more complex language. However, it should be noted that high MLUs in language produced by adults may reflect verbosity, rather than complexity, as their language may still be syntactically simple despite containing many words per utterance. Research findings regarding MLU and syntactic complexity in language produced by individuals with PPA can be found in Table 4.

Table 4- Findings on Mean Length of Utterance (MLU) and Grammaticality of Sentences in PPA

Study	Task	Agrammatic PPA (PPA-G)		Semantic PPA (PPA-S)		Logopenic PPA (PPA-L)		Controls
		n	Finding	*n*	Finding	*n*	Finding	*n*
Ash et al. (2006)	Picture description and Narration of wordless picture book	10	Lowest MLU	13	Lower MLU than controls*	0	N/A	10
Ash et al. (2013)	Picture description	15	Lowest MLU, dependent clauses per utterance, and percent well-formed sentences	18	Reduced percent well-formed sentences compared to controls	29	Reduced percent well-formed sentences compared to controls	12

Study	Task							
Fraser et al. (2014)	Narration of wordless picture book	14	Did not find impaired grammar in all PPA-G participants	10	Produced shorter clauses than controls, but produced more clauses than controls	0	N/A	16
Graham et al. (2004)	Picture description	14	Reduced length of description	0	N/A	0	N/A	11
Knibb et al. (2009)	Semi-structured conversation	15	Low MLU; decreased subordinate clauses, passive constructions, and embedded constructions; grammatical errors	0	N/A	0	N/A	15
Mack et al. (2015)	Narration of wordless picture book	12	Low MLU and percent grammatical sentences compared to controls; verb arguments unimpaired	12	Low percent grammatical sentences compared to controls	11	N/A	12
Meteyard & Patterson (2009)	Interview	0	N/A	8	Increase in omitted prepositions; substitutions of determiners	0	N/A	8
Sajjadi et al. (2012)	Picture description and Interview	0	N/A	16	Reduced MLU compared to controls; equal to controls in syntactic errors	0	N/A	30
Thompson et al., (2012)	Narration of wordless picture book	11	Reduced MLU; impaired percent grammatically well-formed sentences ; impaired verb inflection and verb argument structure compared to controls	6	N/A	20	Reduced MLU and percent grammatically well-formed sentences compared to PPA-S and controls	13
Wilson et al. (2010)	Picture description	14	Lowest MLU; greatest number of syntactic errors, including omitted function words and morphemes	25	Decreased MLU; compared to controls, more embedded sentences than all groups	11	Decreased MLU compared to controls; para-grammatical errors	10

*A nonsignificant trend finding.

In the study by Wilson and colleagues (2010), deceased MLU was reported across all three PPA variants. Other studies found decreased MLU in the narratives produced by participants with PPA, but did not investigate narratives produced by participants across all three types of PPA (Ash et al., 2006; Fraser et al, 2014; Graham et al., 2004; Knibb et al., 2009; Sajjadi et al., 2012). Further research is needed that compares MLU calculations across all three variants of PPA compared to controls, as this measure shows promise in differentially diagnosing individuals with PPA from healthy aging individuals.

Another measure often used to calculate the grammatical complexity of utterances is the proportion of grammatical utterances. This is a measure of grammatical well-formedness. It is calculated by subtracting the number of utterances with grammatical errors from the total number of utterances, divided by the total number of utterances. In the studies analyzed, participants with PPA-G had the lowest percent of well-formed sentences (e.g., omitting function words, impaired verb inflection). Additionally, some studies found that individuals with PPA-S had less well-formed sentences than individuals in the control groups (Ash et al., 2013; Mack et al., 2015; Meteyard & Patterson, 2009). Participants with PPA-L showed a reduced proportion of grammatically correct sentences compared to participants with PPA-S and normal controls; however, additional research is needed (Ash et al., 2013; Thompson et al., 2012).

PPA-L is a relatively recent diagnostic category, and only a small number of studies have compared the syntactic abilities of individuals across the three subtypes of PPA. More comprehensive measures of grammatical ability may be better able to capture to the grammatical deficits present in individuals with PPA and aid in the differential

diagnosis of PPA variants. One such measure of syntactic complexity used in the Thorne and Faroqi-Shah (2016) study is verbs per utterance (i.e., the average number of verbs produced per utterance). Utterances with higher numbers of verbs tend to be more syntactically complex (e.g., they contain embedded clauses and more complex grammatical forms). This measure may be a more accurate indicator of syntactic complexity in individuals with PPA than measures such as MLU, a measure which is based solely on the length of utterances.

While measures of complexity based of verbs may be sufficient to differentiate individuals with PPA-G from individuals with other variants of the disease, a more comprehensive measure of syntax may be more sensitive to syntactic deficits in the other subtypes of PPA. Quantifying syntactic complexity by capturing modifying clauses and passive sentence construction, in addition to embedded clauses, may provide a more comprehensive measure of syntax that may be sensitive to deficits in PPA. Additionally, the analysis of the diversity of morphology used in each narrative sample may be indicative of declines in grammatical abilities. Individuals using few morphological forms (e.g., over-using the –ing form) are likely to produce simplified and repetitive sentence structures.

Despite reporting decreased grammaticality of sentences produced by individuals with PPA, studies often do not report the types of grammatical errors made by participants with PPA. Further research is needed to not only quantify the grammatical errors of these participants, but also to analyze grammatical error types to identify patterns that could be useful in differentiating participants with PPA from healthy aging individuals and individuals with other neurodegenerative diseases. A separate analysis of

the total amount of morphological errors could provide useful information for diagnostic purposes. Individuals with PPA-S and PPA-L are likely to use simplified syntax due to word retrieval difficulties with specific word classes like nouns and pronouns; however, their syntactic abilities generally remain intact in the early stages of the disease. Individuals with PPA-G; however, not only produce simplified syntax, but also incorrect syntax due to errors with verb inflection. More specific error analysis could aid in differentiating a decline in syntactic abilities from deviations in syntactic abilities in order to differentiate between PPA subtypes.

In summary, the following variables may be impaired across all three PPA variants: speech rate, lexical diversity, MLU, and % of grammatical sentences. In the research literature, the focus has primarily been on differentiating between PPA variants, rather than finding commonalities across PPA variants that can be used to differentiate PPA from healthy aging and other related conditions. Further research is needed with this specific goal. Additionally, the different experimental tasks used to elicit connected speech make it difficult to compare findings across studies. Additional research that uses a consistent elicitation task would better enable researchers to compare the language production abilities of individuals with PPA to healthy aging adults and adults with related neurodegenerative diseases.

Language Production in Related Neurodegenerative Conditions

In the early, pre-diagnosis phase of PPA, it can be unclear to persons with PPA, their caregivers, and often their physicians, whether an individual has PPA or another neurodegenerative condition such as Alzheimer's dementia (AD). The 1984 criteria for diagnosing AD relied primarily on memory impairment (McKhann et al., 2011)

However, these criteria were revised in 2011 to reflect an increased understanding of AD over the years (McKhann et al., 2011). Current diagnostic criteria for AD include that cognitive or behavioral symptoms interfere with an individual's ability to function at work or in activities of daily living, they are not explained by a major psychiatric disorder, and that the individual has deficits in two of following five domains: remembering new information, poor reasoning/judgement, visuospatial impairments, impaired language, and changes in personality or behavior (McKhann et al., 2011). Therefore, language deficits can be present in the early stages of the disease, in addition to other cognitive difficulties.

It should also be noted that Mild Cognitive Impairment (MCI) is a diagnostic label for patients with performance between that of healthy aging individuals and people with dementia. A suggested criteria for diagnosing MCI is that the person is neither normal nor demented, there is evidence of cognitive deterioration, and that activities of daily living are impaired (Winblad et al., 2004). Some individuals with MCI may transition to AD (i.e., those with amnestic MCI), and others with MCI may end up with another condition, such as PPA (Petersen, 2004). Language impairments can be seen early on in the disease course, but this does not always occur due to the heterogeneity of deficits in MCI (Taler & Phillips, 2008). A summary of the language differences in healthy aging adults, individuals with AD, and individuals with MCI can be found in Table 5.

Table 5- Comparison of Language in healthy aging, AD, and MCI

Population	Fluency	Word Retrieval	Syntax
Healthy Aging	Similar rates of speech to younger adults, slower speech onset (Spieler & Griffin, 2006) More disfluencies in older adults (Spieler & Griffin, 2006)	Difficulties with low encodable and low frequency word items (Spieler & Griffin, 2006) Subtle decline in word retrieval abilities (Connor et al., 2004)	Gradual decline in syntactic complexity with age (Kemper et al., 2001)
Alzheimer's Dementia (AD)	Fluent but empty speech, some hesitations or delays compared to controls (Forbes, McKay, & Venneri, 2005; Sajjadi et al,, 2012; Tstantali, Economidids, & Tsolaki, 2013)	Difficulties with low frequency word items; semantic paraphasias, circumlocutions compared to controls (Choi et al., 2009; Croot et al., 2000; Emery, 2000; Forbes et al., 2005; McKhann et al., 2011; Sajjadi et al 2012; Taler & Phillips, 2008) Phonology remains intact until middle to late stages of the disease (Croot et al., 2000; Emery, 2000) Decreased idea density compared to controls (Riley et al., 2005)	Produce simplified, but accurate, syntax (Emery, 2000) Total amount of words used remains similar to controls and participants with MCI (Choi et al., 2009; Drummond et al., 2015)
Mild Cognitive Impairment	Similar rates of speech and pauses as controls (Roark et al., 2011)	Produced less concepts in narratives than controls (Choi et al., 2009) Some reporting decreased idea density (Jarrold et al.2010); some reporting idea density remains intact (Roark et al., 2011)	No differences in syntax compared to controls and participants with AD (Choi et al., 2009) MLU and total amount of words used remains similar to controls and participants with AD (Choi et al., 2009; Drummond et al., 2015; Roark et al., 2011)

In regards to fluency, individuals with AD often have fluent but empty speech

(Tsantali, Economidids, & Tsolaki, 2013). They may produce hesitations; however, these

hesitations are often related to impaired semantic systems, with most of their word errors

consisting of semantic paraphasias (Croot et al., 2000; Forbes, McKay, & Venneri, 2005;

McKhann et al., 2011). Circumlocutions may also be present in the speech produced by

individuals with AD, due to deficits in their lexical semantic systems (Croot et al., 2000; Emery, 2000; Sajjadi et al., 2012). Phonology and syntax remain relatively unimpaired in individuals with AD in the early stages of the disease (Tsantali et al., 2013).

It has been found that the linguistic deficits present in individuals with MCI, if present, parallel those found in AD (Choi et al., 2009; Drummond et al., 2015; Jarrold et al., 2010; Roark. Mitchell, Hosom, Hollingshead, & Kaye, 2011; Taler & Philips, 2008). In individuals with MCI, lexical-semantic deficits typically occur early in the course of the disease (Choi et al., 2009; Taler & Phillips, 2008). Although a lexical-semantic deficit could potentially be captured with the use of single-word, standardized tests, research suggests that naming tests alone may be insufficient to differentiate MCI from AD (Bschor et al., 2001). However, MCI is a relatively new diagnostic label, and research on spontaneous speech production in individuals with MCI is limited.

In summary, the primary domain of language affected in MCI and AD is lexical-semantics, in the absence of deficits in fluency, phonology, and syntax. Individuals with MCI present with a milder impairment of semantics than individuals with AD, but the errors made in spontaneous speech are similar (e.g., semantic paraphasias and circumlocutions). Due to the early linguistic deficits experienced by individuals with MCI and AD, the early diagnosis of both MCI and AD and a careful analysis of language properties of these individuals may be helpful in the early differential diagnosis of PPA. Tasks used to quantify the linguistic impairments in MCI and AD have not been used consistently at the level of connected speech, with some researchers using picture description tasks (Bschor et al., 2001; Choi et al., 2009; Forbes et al., 2005), story retelling (Drummond et al., 2015; Roark et al., 2011), and others using patient interviews

(Jarrold et al., 2010). Therefore, it is difficult to draw conclusions from studies that utilize different task designs. Additionally, to the researcher's knowledge, studies have not compared the language impairments in PPA to the language of individuals with MCI and AD based on the analysis of language samples.

Methodological Considerations

Currently, there is little uniformity in which measures are used to quantify language impairments in PPA and related neurodegenerative diseases. Methods that have been suggested include test battery approaches, neuroimaging, and connected language sampling. A test battery approach for subtyping PPA was suggested by Mesulam and colleagues (2009). This approach used two-dimensional template based on an individual's performance the Northwestern Anagram Task, a test of syntax, and the Peabody Picture Vocabulary Test, a test of semantics. However, these tests were recommended for use after a root diagnosis of PPA has been made. Diagnosing PPA variants using a test battery approach requires the use of multiple tests, since many tests focus on single domains of language at a time (e.g., semantics, syntax). These tests tend not to quantify aspects of language that appear to be common throughout all variants of PPA, such as words per minute, lexical diversity, and mean length of utterance, which are measures that can all be derived from connected language samples.

Neuroimaging has also been suggested as a method to diagnose PPA and its variants based on regions of brain atrophy. Each variant of PPA is associated with different regions of cortical atrophy: atrophy associated with PPA- G is typically found in the left inferior frontal gyrus, atrophy in PPA-S is typically found in the anterior left temporal lobe, and atrophy in PPA-L is usually present in the posterior left temporal

cortex (Mesulam et al., 2014). Because individuals with PPA present with language deficits and memory is often spared in the early stages of the disease, it was assumed the pathology behind PPA would not be AD; however, autopsy studies have shown that some variants of PPA (i.e. PPA-L) are linked to AD pathology (Mesulam et al., 2014). Thus, based on neuroimaging alone, it may be difficult to differentiate PPA from related neurodegenerative diseases. Furthermore, although PPA variants show common regions of atrophy, there is heterogeneity in the sites of peak atrophy found and there are not common sites of atrophy across all PPA variants (Mesulam et al., 2014). Individual variability in neurological structures may also make it difficult to determine common sites of peak atrophy across participants. Additionally, the expenses associated with neuroimaging may also make it a less feasible option to use as a diagnostic tool than test batteries and language sampling.

Narrative language, however, provides information regarding more domains of language than single tests or subtests of language, and it is can be done for little to no cost. While previous studies have focused on analyzing connected speech, there is a lack of standardization in the methods used to elicit and analyze narrative speech. There is a need for a standard elicitation technique that can easily be reproduced and that provides a sufficient sample for language analysis. In the following subsections, the Cookie Theft picture description task from the Boston Diagnostic Aphasia Examination (BDAE; Goodglass & Kaplan, 1983) is proposed as a standardized elicitation task, and the use of computerized language analysis is discussed as means of analyzing language samples.

The Picture Description Task

While narrative samples can vary in length depending on the tasks used to elicit them, recent research has shown that short speech samples elicited with a picture description task strongly correlate with lengthier narrative speech samples from the same participants in terms of the number of speech-sound errors, disfluencies, and noun retrieval impairments present in the sample (Ash et al., 2013). Ash and colleagues (2013) investigated the efficacy of a brief evaluation protocol that could be used and analyzed without the need for an experienced linguist. They found that PPA subtypes could quantitatively be distinguished from each other based on the description of the Cookie Theft picture description task from the Boston Diagnostic Aphasia Examination (BDAE; Goodglass & Kaplan, 1983). In this task, participants are asked to describe what is happening in a single picture that shows a kitchen scene where a number of events are occurring. The figure is shown in Appendix A. The results from the picture description task were found to be consistent with each participant's performance from the longer, "Frog, Where Are You?" (Mayer, 1969) narrative produced by each participant. Measures that were found to correlate across tasks included: overall number of speech sound errors, fluency disruptions, the mean length of utterance, dependent clauses per utterance, well-formed sentences per utterance, percent of open class words used, and the proportions of nouns used.

Additionally, although they did not use the Cookie Theft picture description (Goodglass & Kaplan, 1983), Sajjadi and colleagues (2012) reported that a 150-word sample is sufficient for revealing multiple aspects of language decline in semantic dementia (i.e.., PPA-S) and mild Alzheimer's disease (AD) using a picture description

elicitation task. Measures of fluency, semantics, and syntax were calculated and compared between groups. Statistical significance was achieved on the following measures: number of semantic paraphasias, phonological errors, hesitation markers, verb agreement errors, and arguments per verb. Participants with PPA-S produced more semantic paraphasias than the participants with AD and controls. Participants with AD produced more phonological errors, hesitation markers, and verb agreement errors, and used less arguments per verb. Therefore, there is evidence that linguistic measures can be used to differentiate PPA from related neurodegenerative diseases.

The use of picture description to elicit language samples has been criticized because it may result in limited lexical diversity and reduced syntactic complexity compared other narrative tasks. However, previous studies have found statistically significant differences between the narrative productions of participants with PPA and controls, and between the 3 variants of PPA and controls using short picture descriptions (Ash et al., 2013; Bird et al., 2000; Graham et al., 2004; Garrard & Forsyth, 2010; Meteyard & Patterson, 2009; Patterson & MacDonald, 2006; Wilson et al., 2010). If found reliable, brief picture description tasks would have clinical utility in acting as screens for Primary Progressive Aphasia, especially with the use of an automated analysis tool.

Computerized analysis of language samples

Recent studies have examined the ability of software to analyze speech samples, as the process of transcribing and analyzing connected speech is often too time consuming and laborious for practical use in the clinical setting. In a study by Peintner et al. (2008), machine learning was used to automatically diagnose the subtypes of

frontotemporal lobar degeneration (i.e., PPA). This study used computer-based linguistic content analysis (LCA) to calculate idea density. (Kemper et al., 2001; Kemper, Thompson, & Marquis, 2001; Riley et al., 2005; Snowdon, Greiner, & Markesbery, 2000). The researchers also used two software applications on each transcript, the automatic part of speech (POS) tagger (Toutanova, Klein, Manning, & Singer, 2003), which determines frequencies of nouns, verbs, pronouns, etc., and the Linguistic Inquiry and Word Count (LIWC; Pennebaker, Francis, & Booth, 2001), which determines word frequencies organized by different psychological and linguistic dimensions (Peintner et al., 2008). The researchers found that the models they used predicted diagnoses better than random predictor models (*i*.e., randomly choosing from *N* possible classficiations; Peintner et al., 2008). However, this study used interviews with the patients for the narrative samples, which is not a standardized elicitation technique.

Researchers have also investigated the use of computerized analyses of language as a diagnostic tool in patient populations with cognitive impairments and pre-symptomatic AD. In a study by Jarrold et al. (2010), similar techniques were used on narrative transcripts derived from patient interviews. Three linguistic analysis tools were used on these samples: the Part of Speech Tagger (POST; Toutanova et al., 2003), the Linguistic Inquiry Word Count (LIWC; Pennebaker et al., 2001), and CPIDR (Brown, Snodgrass, Kemper, Herman, & Covington, 2008), which measures propositional idea density. In this experiment, findings supported low idea density as a predictor for later AD, as shown in the *Nun Study* (Kemper et al., 2001; Riley et al., 2005; Snowdon et al., 2000).

Additionally, a study by Roark, Mitchell, Hosom, Hollingshead, and Kaye (2011) compared automatic and manual methods to analyze syntactic complexity in healthy participants compared to those with mild cognitive impairments (MCI). The automatic method used was found sufficient to distinguish between the participant groups, suggesting that automated methods may be useful in detecting mild, early changes in language. The manual method of analysis used English syntactic trees to assess linguistic complexity of narratives (Yngve, 1960), and the automated method used the Part of Speech Tagger (Toutanova et al., 2003), the CPIDR program (Brown et al, 2008), and an automatic parser (Charniak, 2000).

More recently, Fraser and colleagues (2014) found that machine learning could distinguish between PPA subtypes. Participants in this study produced the Cinderella Story as a narrative, and the linguistic features of the narratives were calculated using Lu's L2 Syntactic Complexity Analyzer (Lu, 2010). This tool was developed to analyze the syntactic complexity of college-level English from Chinese students (Fraser et al., 2014). Additionally, parse trees were used, along with the POS tagger (Toutanova et al., 2003).

In summary, the method of using software programs to automatically analyze narrative transcripts shows potential for differentially diagnosing PPA from other early stage cognitive and memory impairments and identifying its variants. However, out of the literature reviewed, only two studies used computer analysis to analyze the linguistic impairments in participants with PPA, and they both used different computer programs (Fraser et al., 2014; Peintner et al., 2008). These studies focused only on using computer programs to aid in differentially diagnosing the subtypes of PPA, rather than the

differential diagnosis of PPA compared to related conditions. The computerized

programs in CLAN (MacWhinney, 2000) have been used with great success and

efficiency in many populations including children, bilingual speakers, and individuals

with aphasia, dementia, and traumatic brain injuries (Brundage, Corcoran, Wu & Sturgill,

2016; Faroqi-Shah, 2016; MacWhinney & Fromm, 2016; Ratner & MacWhinney, 2016).

However, to the researcher's knowledge, the CLAN program has not been used to

analyze the language of individuals with PPA compared to healthy aging adults and

adults with related neurodegenerative diseases. The use of computerized programs to

analyze the language of persons with PPA requires further study in order to test their

utility in analyzing the linguistic impairments characteristic of PPA.

The Present Study

The main research question of this study seeks to identify characteristics of

narrative language that are unique to PPA using a semi-automated analysis of a brief

language sample. The study will examine if there are any specific measures derived from

language samples that differentiate PPA from language in healthy aging and other related

conditions such as MCI and mild AD. Given that an isolated language impairment is a

primary symptom of PPA in its early stages, it is expected that an analysis of narrative

language, which is the most complex level of language production, will be sensitive to

linguistic impairments. Based on the existing literature, it is hypothesized that

participants with PPA will show impairments in measures of fluency and syntax when

compared to healthy aging adults and individuals with related neurodegenerative

diseases. Additionally, it is believed that individuals with PPA will produce a higher total

number of errors, as their language abilities not only decline, but deviate from the expected performance of healthy aging individuals and individuals with related neurodegenerative diseases. Individuals with PPA, MCI, and AD are hypothesized to present with lexical-semantic deficits compared to control participants, thus differentiating these groups from healthy aging adults. It is hypothesized that participants with MCI and AD will not be significantly impaired in measures of fluency, phonology, syntax, and overall number of errors, thus differentiating participants with MCI and AD from individuals with PPA. This question will not only isolate which language measures are subdued in PPA, but also the sensitivity and predictive value of each of these measures in the differential diagnosis of PPA.

The second research question of this study seeks to determine which measures of fluency, word retrieval, and syntax best differentiate PPA subtypes based on narrative language samples. While it is expected that all individuals with PPA will have reduced speech rates, MLUs, and % grammatical utterances, additional linguistic measures that have not been used in PPA research will be assessed for their utility in differentiating PPA variants. It is expected that individuals with PPA-G will show linguistic impairment based on measures of fluency (i.e., lowest speech rate) and syntax (i.e., low performance on all measures of syntax and highest number of morphological errors), individuals with PPA-S will show impairment on measures of word retrieval (i.e., lowest performance on all measures and highest number of semantic paraphasias), and individuals with PPA-L will show impairment on measures of fluency (e.g., highest number of disfluencies) and phonology (i.e., highest number of phonemic paraphasias). This question will isolate which language measures are subdued in each PPA variant.

Several methods of assessing the fluency, lexical-semantic/phonological, and syntactic abilities of individuals based on narrative language have been suggested, both in language development and aphasia research (Templin, 1957; Lee, 1974; Malvern & Richards, 1997; MacWhinney, Fromm, Holland, Forbes, & Wright, 2010; Thorne & Faroqi-Shah, 2016). A summary of the measures that will be used in the current study can be found in Table 6.

Table 6 – Measures of Performance

Impairment	Measure	Rationale
Fluency	Words per minute	Lower WPM has been reported in a majority of studies of PPA, either for PPA vs. healthy adults or within subtypes of PPA (Ash et al., 2006, 2013; Graham et al., 2004; Knibb et al., 2009; Mack et al., 2015; Sajjadi et al., 2012; Thompson et al., 2012; Wilson et al., 2010).
	Total number of disfluencies	Individuals with PPA, especially PPA-L, show higher rates of disfluencies (e.g., false starts, fillers, phrase repetitions, etc.) than control participants (Ash et al., 2013; Mack et al., 2015; Wilson et al., 2010).
Word Retrieval	MATTR	Individuals with PPA show decreased lexical diversity compared to controls (Ash et al., 2013; Mack et al., 2015; Thompson et al., 2012; Wilson et al., 2010). MATTR is a measure of lexical diversity that controls for the length of a sample (Covington & McFall, 2010).
	Idea Density	Idea density is a measure of general knowledge and vocabulary that is not dependent on word class, and it is a significant predictor of later life Alzheimer's disease (Kemper et al., 2001; Riley et al., 2005; Snowdon et al., 2000).
	Correct Information Units (CIU)	Proportion of CIU's in a sample is a measure of semantics that captures the informativeness and efficiency of a person's connected speech. This measure has been found to separate aphasic from non-aphasic speakers based on a narrative sample (Nicholas & Brookshire, 1993). Additionally, circumlocutions are associated with PPA-S (Ash et al., 2013; Sajjadi et al., 2012).
	Total number of semantic errors	Semantic paraphasias are associated with PPA-S (Ash et al. 2013; Sajjadi et al., 2012).
	Total number of phonological errors	Phonemic paraphasias are associated with PPA-L (Gorno-Tempini et al., 2011).
	Total number of word retrieval errors	Total number of semantic and phonological errors is more likely to capture word retrieval deficits in PPA, since different error types are associated with different PPA variants.

Syntax	Mean length of utterance (MLU)	Reduced MLU is often reported in individuals with PPA, especially in PPA-G (Ash et al., 2006, 2013; Graham et al., 2004; Knibb et al., 2009; Mack et al., 2015; Sajjadi et al., 2012; Thompson et al, 2012; Wilson et al., 2010).
	Proportion of grammatical utterances	Participants with PPA produce less well-formed sentences than controls (Ash et al., 2013; Mack et al., 2015). This is a global measure of grammatical well-formedness that has been found to be reliable in aphasia research (Saffran et al., 1989; Berndt et al., 2000).
	Verbs per utterance	This measure captures syntactic complexity. This is proposed as a measure to capture deficits in PPA-G.
	Sentence Complexity	This is a measure of syntactic abilities that accounts for syntactic complexity based on the use of embedded clauses, modifying clauses, and passive sentence construction. This measure is proposed as a more comprehensive measure of syntax that may be sensitive to deficits in PPA.
	Total number of morphological errors	Increased morphological errors (e.g., verb inflection) are often reported in individuals with PPA, especially PPA-G (Knibb et al., 2009; Thompson et al., 2012; Wilson et al., 2010).
General	Total number of errors	Individuals with PPA produce speech with more disfluencies, word retrieval errors, and grammatical/morphological errors than controls and individuals with related neurodegenerative diseases.

To summarize, measures of fluency, lexical-semantics, and syntax have been selected as potential indicators of linguistic impairment in PPA for this study. Using these measures to analyze the linguistic abilities of participants provides a consistent way to quantify their linguistic abilities, based on spoken language samples.

Methods

This study was a retrospective analysis of data from the *Transcranial Direct Current Stimulation (tDCS) for Primary Progressive Aphasia* study at Johns Hopkins University and the DementiaBank database (https://talkbank.org/DementiaBank/; Becker, Boiler, Lopez, Saxton, & McGonigle, 1994). The tDCS study at Johns Hopkins examines the effects of tDCS during language therapy in people with PPA (PI: Tsapkini). Pre-tDCS

language samples collected during initial assessments were utilized for this study. Data for all groups were collected according to a pre-specified protocol, with the Cookie Theft picture description and demographic data available from each participant.

Participants

Twenty-six people (14 males, 12 females) with PPA (10 with PPA-G, 9 with PPA-L, 7 with PPA-S) were selected from the tDCS for Primary Progressive Aphasia study data pool. Persons with a diagnosis of PPA as per neurologist report (neurologists included Hillis, Onyike, Mesulam) were referred to participate in this study. Each diagnosis of PPA was confirmed through discussions of symptoms among Hillis, Onyike, and Tsapkini. All participants with PPA were right-handed English-speakers who had received at least a 9th grade education. According to the study's recruitment protocol, no participants with a history of stroke or other neurological disorders, language-based learning disorders, or a quotient score of less than 30 on the Western Aphasia Battery were included. Subtypes of PPA were determined by Tsapkini and lab members based on each participant's performance on a pre-determined test battery.

Twenty-four control participants (10 males, 14 females), 20 participants with Mild Cognitive Impairment (MCI; 10 males, 10 females), and 20 participants with Alzheimer's Dementia (AD; 10 males, 10 females) were selected from the DementiaBank database (Becker, Boiler, Lopez, Saxton, & McGonigle, 1994). According to the protocol administered by the Alzheimer and related Dementias Study at the University of Pittsburgh School of Medicine (Becker et al., 1994), control participants had no history of a neurological condition, a cognitively deteriorating condition, or depression. For participants with MCI and AD, inclusion required that all participants be above 44 years

of age, have at least 7 years of education, no history of nervous system disorders, have a

Mini-Mental State Exam (MMSE) score of 10 or greater, and be able to give informed

consent. These participants received neuropsychological and physical assessments, and in

1992 each patient was given a final diagnosis based on their clinical record and additional

information available (e.g., autopsy; Becker, 1994).

Experimental and control groups were matched for age and education level. Table

7 shows the age and education mean values for each group.

Table 7 – Age and Education Data for Experimental and Control Groups

	PPA (n=26)	Controls (n=24)	MCI (n=20)	AD (n=20)
Age (years)	68.62 (7.79)	68.75 (7.21)	66.10 (9.18)	68.00 (7.37)
Education (years)	16.12 (2.92)	15.04 (2.87)	14.65 (3.27)	14.55 (2.37)

One-way analysis of variance (ANOVA) tests revealed no significant differences

among the groups on age, $F(1,3) = 0.511, p > .05$ or years of education, $F(1,3) = 1.48, p$

$> .05$.

Language Analysis

Narrative sample

This study used a language sample from each participant elicited by the Cookie

Theft picture description from the Boston Diagnostic Aphasia Examination (BDAE;

Goodglass & Kaplan, 1983). This was the only language sample available for all four

populations. This task has a standardized administration procedure, provides a clear

focus, and contains contents that are familiar to all subjects. Additionally, it is a brief task

to administer, which would make it an efficient and informative measure to use in a

clinical setting. It has been demonstrated that brief speech samples are strongly

correlated to lengthier narrative speech samples, and may be sufficient for differentiating the 3 principal forms of PPA (Ash et al., 2013).

Transcription and coding

Narrative samples from participants with PPA were transcribed using CHAT conventions (MacWhinney, 2000). Narrative samples from the DementiaBank database (Becker et al., 1994) were previously transcribed in CHAT (MacWhinney, 2000) by the researchers who collected the recordings. Each transcript was double-checked for accuracy using the original audio files. Codes from the CLAN manual (http://childes.psy.cmu.edu/manuals/Clin-CLAN.pdf) and Coding Cheat Sheet on AphasiaBank (http://aphasia.talkbank.org/) were added to capture errors such as disfluencies (e.g., fillers, whole word repetitions, part word repetitions), word retrieval errors (e.g., semantic paraphasias, phonemic paraphasias, neologisms, etc.), syntactic errors (e.g., the omission of function words, verb inflection errors), and morphosyntactic errors (e.g., verb inflection errors). Syntactic errors and morphosyntactic errors were both coded separately since sentences containing grammatical errors were used to calculate the proportion of grammatical utterances, a more global measure of syntax, and morphosyntactic errors were used to investigate if verb inflection is specifically impaired in PPA. Additional codes were created to capture other potential deficits in PPA. The [* sp:m] code was created to capture mixed paraphasias (i.e., containing both semantic and phonological errors), the [+ sce] code was created to mark sentences that were semantically incorrect (e.g., "The boy is in the cookie jar."), and the [+ comp] code was created to mark sentences with more complex construction (i.e., sentences containing

embedded clauses, qualifiers, and passive construction). A list of all codes used in the study can be found in Appendix B.

Task clarification questions were not coded and excluded from further analysis (e.g., "Can I look at it and tell you?"). Various programs from CLAN (MacWhinney, 2000) were used to extract various language measures, as outlined in Table 8. Two measures, speech rate and CIUs, were calculated manually outside of CLAN. In order to calculate rate of speech, the duration of the audio sample for 5 consecutive utterances was measured using the Praat program (Boersma, 2001). The total number of intelligible, whole words (i.e., no phonological fragments, fillers, or paraphasias) was counted manually. Correct information units were calculated by manually counting the total number of words in a sample, and then counting the number of CIUs based on criteria outlined by Nicholas & Brookshire (1993). The proportion of CIUs was calculated by dividing the number of CIUS by the number of words in the sample.

Table 8 – Measures and Software Analysis

Measure	How derived?/CLAN utility	Formula for final measure
WPM	Total number of intelligible, whole words per 5 utterance segment was manually counted and divided by the speaker's total speaking time as measured in Praat (Boersma, 2001).	Total # of words/total length of audio in minutes
Total number of disfluencies	Manual coding of disfluencies; FREQ	Add totals of each disfluency type.
MATTR	FREQ program	A window length of x is set based on the smallest number of FREQ tokens found in the sample. A TTR for tokens 1 to x is estimated, then for tokens 2 to (x+1), then 3 to (x+2) and so on, for the entire sample. The final score is an average of TTR's.
Idea Density	EVAL	# of propositions (non-noun entities)/ 10 words

Proportion CIU's	Manually calculated	Total # correct information units/ Total # words in sample
Total number of semantic errors	Manual coding of semantic paraphasias; FREQ	Add totals of each semantic error type.
Total number of phonological errors	Manual coding of phonological paraphasias, phonemic paraphasias, neologisms; FREQ	Add totals of each phonological error type.
Total number of mixed errors	Manual coding of mixed paraphasias, FREQ	Add all mixed paraphasias.
Total number of word retrieval errors	Manual coding of word retrieval errors; FREQ	Total # of semantic errors + total # of phonological errors + total # of mixed errors
Mean Length of Utterance	EVAL	Total # of morphemes in a sample/ total # of utterances in a sample
Prop. Grammatical utterances	Manual coding of grammaticality of each utterance; EVAL	(Total # utt - # utt with errors)/ Total # utt
Verbs per utterance	EVAL	Average # verbs/ Total # utt
Sentence Complexity	Manual coding of complex sentence types (e.g., sentences containing embedded clauses, modifying clauses, passive sentence construction), FREQ	Add all sentences marked as complex.
Total number of morphological errors	Manual coding of morphological errors; FREQ	Add all morphological errors

Inter-rater reliability

A subset of the narratives produced by each participant group (10-20% of the transcripts per group) was randomly chosen to be independently transcribed and coded by an additional researcher, using the original audio files and operational definitions of codes that can be found in Appendix B. To compare the reliability of transcriptions, intra-class correlations (ICC) were calculated. ICCs were used rather than Kappa statistics because, unlike Cohen's kappa which quantifies reliability based on complete agreement, ICCs use the magnitude of disagreement to calculate reliability estimates (Hallgren, 2012). A high degree of reliability was found between researchers. The

average ICC measure for the total number of utterances was 0.937 with a 95% confidence interval from 0.840 to 0.976, $F(2, 18) = 15.895$, $p < .01$. The average ICC measure for coding reliability (i.e., total number of codes used per sample) was 0.989 with a 95% confidence interval from 0.949 to 0.997, $F(2, 8) = 77.530$, $p < .01$. The random sample of narratives was also checked for CIU reliability, calculated manually based on the rules outlined by Nicholas & Brookshire (1993). The average ICC measure for CIUs was 0.998 with a 95% confidence interval from 0.995 to 0.999, $F(2,18) = 473.442$, $p < .01$. Any disagreements were resolved by re-listening to samples and reaching a consensus between transcribers.

Statistical Analysis

Statistical analyses were performed with SPSS version 24 with a p value for significance set at $p < .01$. A more conservative p value was used in order to account for the multiple statistical comparisons in this study. For each measure, the four groups (i.e., controls, PPA, MCI, and AD) were analyzed using one-way ANOVAs and Tamhane's T2 post-hoc tests. The Levene's test indicated that the subgroups of PPA (i.e., PPA-G, PPA-L, PPA-S) did not meet the requirement of homogeneity of variance for parametric statistical tests, so the Kruskal-Wallis non-parametric test was used to for the within-groups comparison of linguistic measures. All significant tests were compared with post-hoc t-tests corrected for multiple comparisons.

Results

Between-groups Comparisons

Results of linguistic measures based on each participant's picture description samples are summarized in Table 9.

Table 9 – Results of Between-groups Comparisons

	PPA	Controls	MCI	AD
Fluency Measures				
Avg WPM	76.9 (39.5)[a, b]	141.7 (39.5)	123.8 (31.2)	116.6 (42.8)
Total Disfluencies	27.6 (19.2)[a, b]	9.46 (7.11)	10.5 (9.26)	12.9 (13.8)
Word Retrieval Measures				
MATTR	0.83 (0.08)	0.86 (0.03)	0.86 (0.04)	0.87 (0.04)
Idea Density	0.40 (0.08)	0.41 (0.04)	0.39 (0.04)	0.40 (0.06)
Proportion CIUs	0.63 (0.17)[a, b]	0.82 (0.10)	0.80 (0.12)	0.72 (0.18)
No. Semantic Errors	0.46 (0.81)	0.00 (0.00)	0.00 (0.00)	0.25 (0.91)
No. Phonological Errors	0.69 (1.29)	0.04 (0.20)	0.00 (0.00)	0.05 (0.22)
Total Word Retrieval Errors	1.23 (1.75)[a*, b]	0.04 (0.20)	0.00 (0.00)	0.30 (0.92)
Syntax Measures				
MLU, morphemes	9.85 (3.81)	9.93 (2.12)	11.05 (2.94)	9.67 (2.89)
Proportion grammatical utterances	0.66 (0.28)[a, b]	0.89 (0.16)	0.89 (0.13)	0.82 (0.18)
Verbs/utterance	1.40 (0.69)	1.22 (0.27)	1.30 (0.36)	1.23 (0.45)
Complex Utterances	0.08 (0.27)	0.47 (1.02)	0.60 (0.75)	0.35 (0.59)
Total Morphological Errors	0.50 (0.99)	0.04 (0.20)	0.05 (0.22)	0.20 (0.65)
General				
Total Errors	29.31 (19.80)[a, b]	9.54 (7.16)	10.55 (9.23)	13.40 (14.78)

Mean (SD) for measures in between groups comparisons. Abbreviations: PPA= Primary Progressive Aphasia (all subtypes); MCI= Mild Cognitive Impairment; AD= Alzheimer's Dementia.

[a] Differs from controls at $p < .01$

[b] Differs from MCI $p < .01$

[c] Differs from AD $p < .01$

* $p = 0.012$

Fluency measures

Speech rate showed a main effect of group, $F(1,3) = 12.615$, $p < .01$. Speech rate was reduced in participants with PPA compared to controls and participants with MCI (PPA compared to controls, $p < .001$; PPA compared to MCI, $p < .001$). Due to the stringent criteria set by the study, speech rate was not significant between the PPA group

and the AD group ($p = .015$). The total number of disfluencies produced was also statistically significant, $F(1,3) = 9.713$, $p < .01$. Participants with PPA produced a greater number of disfluencies per sample than control participants ($p = .001$) and participants with MCI ($p = .002$). A post-hoc analysis of disfluency types revealed that participants with PPA produced more prolongations ($p = .001$), word repetitions ($p = .008$), and filled pauses ($p = .004$) than controls. Additionally, participants with PPA produced more prolongations ($p = .001$), phonological fragments/false starts than participants with MCI ($p = .012$), and more filled pauses that participants with AD ($p = .001$).

Word retrieval measures

The proportion of CIUs per sample showed a main effect of group, $F(1,3) = 8.748$, $p < .01$. Participants with PPA had lower CIU scores than controls ($p = .000$) and participants with MCI ($p = .001$). The total number of word retrieval errors also showed a main effect of group, $F(1,3) = 7.437$, $p < .01$. Participants with PPA produced more word retrieval errors than control participants ($p = .012$) and participants with MCI ($p = .009$).

Syntactic measures

The proportion of grammatical utterances was the only measure to show a main effect of group, $F(1,3) = 6.923$, $p < .01$. Participants with PPA produced fewer grammatically well-formed sentences than controls ($p = .006$) and participants with MCI ($p = .005$).

General measures

The total number of errors in a sample showed a main effect of group, $F(1,3) = 10.828$, $p < .01$. Participants with PPA produced more errors per narrative (i.e.,

disfluencies, word retrieval errors, and grammatical errors) than control participants ($p =$ .000) and participants with MCI ($p = .001$).

To summarize, the following linguistic measures were found to be statistically significant in differentiating participants with PPA from healthy controls and participants with MCI: speech rate, total number of disfluencies, proportion of CIU's, total number of word retrieval errors, proportion of grammatical utterances, and total number of errors in the sample. No measures were found to be statistically significant in differentiating participants with PPA from AD.

Cut-off scores, sensitivity, and specificity

PPA compared to Controls

For the statistically significant measures, cut-off scores for the diagnosis of PPA were determined based on the distribution of control data, using a confidence interval of difference of 0.95. For measures in which the PPA group had higher values than the control group, the upper bound of the control group's performance was added to the control group's mean score. For measures in which the PPA group had lower values than the control group, the lower bound of the control group's performance was subtracted from the control group's mean score. Sensitivity values (i.e., how well the cut-off score detects a true positive) and specificity values (i.e., how well the cut-off score excludes a true negative) were then calculated in order to assess the efficacy of each cut-off score in confirming the diagnosis of PPA. Additionally, z-scores were calculated for each group, based on the control group's performance on each linguistic measure. Z-scores show how many standard deviations above or below the mean of the normative group an individual is performing. The findings are summarized in Table 10.

Table 10 - Sensitivity and Specificity of Cut-off Scores for PPA vs. Controls

Measure	Control Mean	Control SD	95% Cut Off	Sensitivity	Specificity	Z-score
WPM	141.73	39.46	< 98.60	65.38	79.19	-1.64
Total Disfluencies	9.46	7.12	> 19.99	57.69	95.83	2.54
Proportion CIUs	0.82	0.1	< 0.71	65.38	87.50	-1.45
Total Retrieval Errors	0.04	0.2	> 0.64	53.85	95.83	5.95
Prop. Grammatical Utt.	0.89	0.16	< 0.78	57.69	83.33	-1.44
Total Errors	9.54	7.16	> 21.45	57.69	95.83	2.76

As is shown in Table 10, none of the measures were significantly sensitive (over 75% accurate in detecting a true positive) to the diagnosis of PPA. However, the measures with the highest sensitivity scores were words per minute and the proportion of CIUs. Specificity values were higher than sensitivity values for all measures (over 75% accurate in detecting a true negative), suggesting that these cut-off scores are better at excluding true negatives (i.e., identifying controls) than they are at detecting true positives (i.e., identifying a participant with PPA). The highest specificity values were found for total disfluencies, total retrieval errors, and total errors. Z-scores for each measure also showed that the performance of participants with PPA is furthest from that of control participants on the measures of total disfluencies, total retrieval errors, and total errors.

PPA compared to MCI

For measures in which participants with PPA differed significantly from participants with MCI, cut-off scores were determined based on the performance of the MCI participants in order to evaluate the accuracy of a more stringent cut-off score in the

differential diagnosis of PPA from related neurodegenerative conditions. The findings are summarized in Table 11.

Table 11- Sensitivity and Specificity of Cut-off Scores for PPA vs. MCI

Measure	MCI Mean	MCI SD	95% Cut Off	Sensitivity	Specificity
Avg WPM	123.80	31.20	< 99.74	65.38	75.00
Total Disfluencies	10.5	9.26	> 19.51	57.69	85.00
CIU	0.8	0.12	< 0.71	65.38	80.00
Total Retrieval Errors	0.00	0.00	> 0.61	53.85	100.00
Prop. Grammatical Utt	0.89	0.13	< 0.78	57.69	80.00
Total Errors	10.55	9.23	> 21.06	57.69	87.50

Based on the data in Table 11, no measures were shown to be significantly sensitive to the diagnosis of PPA (over 75% sensitive). The most sensitive measures were shown to be speech rate and CIUs. Specificity values were found to be higher than sensitivity values for all measures (over 75% specificity), with the total number of retrieval errors being the most specific measure for identifying control participants.

PPA compared to AD

None of the measures tested were statistically significant in differentiating PPA from AD.

Within-group Comparisons

Results of the Kruskal-Wallis non parametric test for within-groups comparisons on linguistic measures based on each participant's picture description samples are summarized in Table 12.

Table 12 - Results for Within-groups Comparisons

	PPA -G	PPA-L	PPA-S
Fluency Measures			
Avg WPM	43.7 (17.7)[b,c]	85.1 (31.1)[a]	113.8 (34.0)[a]
Total Disfluencies	28.8 (22.4)	33.3 (17.7)	8.43 (14.4)
Word Retrieval Measures			
MATTR	0.79 (0.12)	0.85 (0.56)	0.87 (0.03)

Idea Density	0.34 (0.06)[b,c]	0.44 (0.08)[a]	0.43 (0.45)[a]
Proportion CIUs	0.66 (0.16)	0.63 (0.18)	0.59 (0.17)
No. Semantic Errors	0.40 (0.70)	0.33 (0.71)	0.71 (1.11)
No. Phonological Errors	0.90 (1.29)	0.67 (1.66)	0.43 (0.79)
Total Word Retrieval Errors	1.40 (1.84)	1.00 (1.66)	1.29 (1.98)
Syntax Measures			
MLU, morphemes	6.51 (2.96)[b,c]	12.44 (2.78)[a]	11.30 (2.45)[a]
Proportion grammatical utterances	0.51 (0.33)	0.71 (0.25)	0.81 (0.15)
Verbs/utterance	0.75 (0.48)[b,c]	1.80 (0.43)[a]	1.82 (0.46)[a]
Complex Utterances	0.00 (0.00)	0.11 (0.33)	0.14 (0.38)
Total Morphological Errors	0.40 (0.70)	0.78 (1.40)	0.29 (0.76)
General			
Total Errors	30.6 (22.4)	35.1 (18.7)	20.0 (16.2)

Mean (SD) for measures in between groups comparisons. Abbreviations: PPA-G = agrammatic PPA; PPA-L = logopenic PPA; PPA-S = semantic PPA.

[a] Differs from PPA-G at $p < .01$

[b] Differs from PPA-L at $p < .01$

[c] Differs from PPA-S at $p < .01$

For the within-groups comparison, four linguistic measures were shown to be statistically significant. Kruskal-Wallis (K-W) ANOVAs showed significant group effects for average WPM (K-W $\chi^2 = 15.016$, $df = 2$, $p < .01$), idea density (K-W $\chi^2 = 11.043$, $df = 2$, $p < .01$), MLU based on morphemes (K-W $\chi^2 = 13.987$, $df = 2$, $p < .01$), and verbs/utterance (K-W $\chi^2 = 16.487$, $df = 2$, $p < .01$). Follow-up pairwise comparisons were conducted for each of the statistically significant measures for the three PPA groups.

Compared to both PPA-L and PPA-S groups, participants with PPA-G were shown to have decreased WPM rates (PPA-G versus PPA-L, $p = .006$; PPA-G versus PPA-S, $p = .001$), idea density (PPA-G versus PPA-L, $p = .007$; PPA-G versus PPA-S, $p = .003$), MLU (PPA-G versus PPA-L, $p = .001$; PPA-G versus PPA-S $p = .007$), and verbs/utterance (PPA-G versus PPA-L, $p = .000$; PPA-G vs. PPA-S $p = .001$). No

measures were shown to have statistical significance between the PPA-L and PPA-S groups.

Discussion

The present study examined fluency, word retrieval, and syntactic production in individuals with PPA compared to individuals with related neurodegenerative diseases by analyzing speech samples derived from Cookie Theft picture description (BDAE; Goodglass & Kaplan, 1983). The primary purpose of the study was to determine if any specific measures derived from language samples could differentiate participants with PPA from healthy aging adults and adults with related conditions such as MCI and AD. Participants with PPA were found to produce lower speech rates, proportion of Correct Information Units, and proportion of grammatical utterances than controls and participants with MCI, and a higher number of disfluencies and total number of errors, particularly word retrieval errors. These findings indicate that although different impairments are characteristic of each subtype of PPA, there are some aspects of language that are impaired across PPA subtypes. Additionally, these findings indicate that while the language of participants with MCI remains similar to that of control participants, there are linguistic impairments in AD, most notably in word retrieval, that may make it difficult to differentiate from language in PPA.

The second goal of this study was to determine which measures of fluency, lexical-semantics, and syntax best differentiate PPA subtypes from each other. The main findings were that participants with PPA-G showed impairments in measures of fluency,

semantics, and syntax, while participants with PPA-L did not show any statistically significant differences from participants with PPA-S. These findings will be discussed in detail in the following sections.

PPA versus Healthy Controls, MCI, and AD

Previous research has shown that healthy aging adults maintain speech rates similar to those produced by younger adults (Speiler & Griffin, 2006). Although previous studies have not compared speech rates in PPA as a group compared to healthy aging adults, the present study supports research that has shown that there is a reduced rate of speech in participants with specific subtypes of PPA relative to healthy aging adults (Ash et al., 2006, 2013; Fraser et al., 2014; Graham et al., 2004; Mack et al., 2015; Sajjadi et al., 2012; Thompson et al., 2012; Wilson et al., 2010). Additionally, this study supports research that has shown that participants with MCI produce similar rates of speech as healthy aging controls (Roark et al., 2011). Thus, these findings suggest that speech rate may not only be a useful differentiator of PPA subtypes, but also for PPA versus healthy aging and MCI.

While a decline in linguistic abilities is expected in healthy aging, a deviation in linguistic abilities is characteristic of PPA. Although older adults produce more disfluencies than younger adults (Bortfeld et al., 2001; Speiler & Griffin, 2006), research has shown that there is an increase in disfluencies in some subtypes of PPA compared to healthy aging adults (Ash et al., 2013; Mack et al., 2015; Wilson et al., 2010). This study supports these findings and extends them to PPA compared to healthy aging adults and adults with MCI. Thus, participants with PPA not only have inefficient language systems

compared to controls (i.e., slower speech rates), but also impaired systems that result in a higher number of errors in fluency, in addition to reduced fluency in regards to speech rate.

Interestingly, although individuals with AD have been shown to produce fluent but empty speech (Tsantali, Economidids, & Tsolaki, 2013), this study did not find a significant difference between the speech rate and total number of disfluencies produced by participants with AD and participants with PPA. This finding may be explained by the neuropathologies of PPA compared to AD. While the sites of neural atrophy in PPA vary for each subtype, research has shown that atrophy generally occurs in the left inferior frontal gyrus in PPA-G, in the left posterior temporal areas of the language network for PPA-L, and in the anterior left temporal lobe for PPA-S (Mesulam, 2014). Persons with AD have been found to have atrophy primarily in the temporal lobe, within the hippcampo-entorhinal cortex system. This suggests that reduced fluency in AD may be due to impaired semantic systems, with hesitations and pauses reflecting word retrieval difficulties (Croot et al., 2000; Forbes, McKay, & Venneri, 2005; McKhann et al., 2011). Therefore, when considering participants with PPA as a group relative to AD, some subtypes of PPA with similar regions of atrophy as AD can make differentiating the two diseases challenging. While measures of fluency have been used to capture the deficits in PPA-G, which is characterized by impaired motor planning for speech due to frontal lobe atrophy, and PPA-L which is characterized by hesitations and false starts, the present study suggests that deficits in fluency may also reflect impaired semantic systems due to temporal atrophy.

This pattern was also seen in measures of word retrieval. The findings of the present study support previous research showing that participants with some subtypes of PPA have word retrieval impairments relative to healthy controls (Ash et al., 2006; Kavé et al., 2007; Mack et al., 2015; Meteyard & Patterson, 2009; Sajjadi et al., 2012; Thompson et al., 2012; Wilson et al., 2010). Additionally, this study found that word retrieval is impaired in PPA relative to MCI. The performance of participants with PPA was not statistically significant compared to the AD group on measures that had achieved significance among the other groups (i.e. the proportion of Correct Information Units and total number of word retrieval errors). This result is consistent with studies that have shown that participants with AD have difficulties retrieving low frequency word items, produce semantic paraphasias, and produce more circumlocutions (captured by the proportion of CIUs) than controls (Choi et al., 2009; Croot et al., 2000; Emery, 2000; Forbes et al., 2005; McKhann et al., 2011; Sajjadi et al., 2012; Taler & Philips, 2008). As previously stated, it is likely these difficulties in PPA and AD are due to impaired semantic systems resulting from atrophy in the temporal lobe.

With regards to measures of syntax, the proportion of grammatical utterances was the only measure shown to differentiate the performance of the PPA group from the control and MCI groups. This finding supports previous studies which have found that participants with PPA produce fewer grammatically correct sentences than controls (Ash et al., 2013; Mack et al., 2015; Thompson et al., 2012; Wilson et al., 2010). However, previous studies looked at the proportion of grammatical sentences produced by participants with each subtype of PPA compared to the control group, rather than the performance of the entire PPA group relative to controls. This finding suggests that the

proportion of grammatical utterances is not only a useful measure of differentiating PPA subtypes, but it is also a useful measure in differentiating individuals with PPA from healthy aging adults and people with MCI. However, this measure was not found to be significant between the PPA and AD groups. Previous research has shown that participants with AD produce simplified, but accurate syntax (Emery, 2000). This study did not replicate this finding, suggesting that syntactic abilities do become impaired throughout the course of the disease, although the initial linguistic impairments are often due to impaired semantic systems.

The total number of errors produced across linguistic domains was also found to be significant in differentiating PPA from healthy aging and MCI. These findings support that PPA can be differentiated from healthy aging by looking at measures of linguistic impairment, rather than just measures of linguistic decline, which are often not sensitive to the detection of impairments due to neurological conditions compared to typical aging.

To summarize, this study has found that the measures of speech rate, total number of disfluencies, proportion of CIUs, total number of word retrieval errors, proportion of grammatical utterances, and the total number of errors may be useful in differentiating PPA from healthy aging and MCI. However, these measures were not sufficient to capture PPA relative to AD, suggesting that commonalities in sites of neural atrophy may result in similar impairments between PPA and AD in word retrieval.

Additionally, the findings of the present study suggest that participants with AD may eventually have compromised syntactic systems in addition to semantic systems. While cognitive deficits are typically the focus of research on individuals with AD, the

findings of this study suggest that individuals with AD potentially have as many issues with language as individuals with PPA, with their semantic deficits affecting their speech rate, and impaired syntactic skills affecting their ability to produce grammatically correct sentences. Thus, for the differential diagnosis of PPA relative to AD, performance on cognitive measures must also be considered. Participants with AD have cognitive difficulties in addition to linguistic impairments early in the course of the disease (McKhann et al., 2011), whereas individuals with PPA present with linguistic impairments in the absence of cognitive deficits early in the disease (Gorno-Tempini et al., 2011).

PPA-G versus PPA-L versus PPA-S

Participants with PPA-G were shown to have significantly lower speech rates than participants with PPA-S and PPA-L. This replicates previous findings that individuals with PPA-G have the most impaired fluency of all PPA variants (Ash et al., 2006, 2013; Fraser et al., 2014; Graham et al., 2004; Mack et al., 2015; Thompson et al., 2012; Wilson et al., 2012). Due to the prevalence of atrophy in the left inferior frontal gyrus in PPA-G, where Broca's area is located, it is not surprising that fluency is impaired in this subtype of PPA due to the motor speech programming difficulties that often occur with damage or atrophy in Broca's area. Speech rate was not shown to be significant in differentiating PPA-L from PPA-S, although participants with PPA-L generally had lower speech rates than participants with PPA-S. The lack of significance may reflect the more similar sites of atrophy found in these two variants of PPA, with temporal involvement resulting in impaired word finding abilities. Although PPA-L is characterized by atrophy in the left posterior temporal components of the language

network, and PPA-S is associated with atrophy in the left anterior posterior temporal lobe, both of these areas play a role in word retrieval.

With regards to measures of semantics, idea density was the only measure found to be significant. However, this measure was only significant in differentiating PPA-G from the other variants, with PPA-G participants scoring lower than the other participant groups. While PPA-S and PPA-L are characterized by word retrieval deficits and were expected to have lower scores on this measure, idea density appears to capture reduced expression rather than word retrieval difficulties specifically. As previous studies have suggested, it is possible that idea density does not purely measure semantic ability since it counts "propositions" as non-noun entities (Brown et al., 2008; Thorne & Faroqi-Shah, 2016). Participants with PPA-S have been shown to use fewer nouns than participants with other subtypes of PPA, and it has also been suggested that participants with PPA-L have noun deficits (Ash et al., 2013; Mack et al., 2015; Thompson et al., 2012; Wilson et al., 2010). It is likely that the PPA-G group's agrammatism resulted in a reduced output that consisted primarily of nouns, resulting in low scores on this measures in relation to the other subtypes of PPA when all non-noun entities were removed from each sample for this calculation.

Participants with PPA-G had the lowest MLUs of all subtypes, replicating previous research findings (Ash et al., 2006; Ash et al., 2013; Knibb et al., 2009; Mack et al., 2015; Thompson et al., 2012; Wilson et al., 2012). The PPA-G group was also found to produce a lower number of verbs per utterance than the other groups. This supports previous findings that participants with PPA-G have word retrieval impairments specific to verbs, resulting in the use of a high number of nouns relative to verbs in speech (Ash et

al., 2013; Fraser et al., 2014). Thus, the present study found that both fluency and grammar were impaired in PPA-G participants. However, it should be noted that the neurological bases of impairments of fluency and grammar in PPA-G do not necessarily overlap, with impairments of grammar associated more with atrophy in the main body of the inferior frontal gyrus, and impairments of fluency are associated with the dorsal rim of the inferior frontal gyrus and parts of the premotor cortex (Sahin, Pinker, Cash, Schomer, & Halgren, 2009). Additionally, previous studies have found that MLU was reduced in PPA-L relative to controls (Thompson et al., 2012; Wilson et al., 2010) and PPA-S relative to controls (Sajjadi et al., 2012; Wilson et al., 2010); however, MLU was insufficient for differentiating PPA-L and PPA-S from one another in the present study. This is consistent with the subtyping criteria for PPA, in which PPA-L and PPA-S retain intact syntactic abilities early in the course of the disease (Gorno-Tempini et al., 2011).

To summarize, the following linguistic measures were useful in differentiating PPA-G from the other variants of PPA: speech rate, idea density, MLU, and verbs per utterance. These measures captured the specific deficits of PPA-G in fluency and syntax. However, these measures were not sufficient in differentiating PPA-L from PPA-S, likely due to the more common sites of neural atrophy in PPA-L and PPA-S in the temporal lobe in regions associated with word retrieval abilities. The measures of word retrieval tested were not sensitive enough to detect the difference in word retrieval between the two subtypes (i.e., phonological difficulties in PPA-L and semantic difficulties in PPA-S). Although measures of fluency were expected to be able to differentiate PPA-L from PPA-S in the present study, these measures did not reach significance.

Clinical Implications

Previous approaches to quantifying the linguistic impairments in PPA have focused on identifying subtypes of PPA after a root diagnosis of PPA has been made, rather than on differentially diagnosing PPA from healthy aging and related neurodegenerative conditions. The findings of this study support the idea that there are linguistic measures with a high clinical likelihood of differentiating PPA from healthy aging and MCI with the use of a brief picture description task protocol. Thus, using narrative language samples shows potential clinical utility in contributing to the differential diagnosis of PPA related to healthy aging and MCI. While the sensitivity values of the proposed cut-off scores were not significantly high, this is not necessarily problematic because clinically, a narrative sample would never be used as the sole basis for a diagnosis. Rather, this study suggests that narrative language samples help inform a diagnosis, and it is expected information derived from narrative samples would be used in conjunction with a combination of language tests in order to determine an individual's diagnosis and identify potential treatment targets.

Unlike AD, healthy aging and MCI are difficult to differentially diagnose from PPA due to the limited cognitive components of each group. Although no linguistic measures were found to reach significance between PPA and AD, the cognitive impairments in AD allow for differential diagnosis using cognitive testing.

Additionally, after a diagnosis of PPA has been made, the measures tested in the current study show utility in the diagnosis of PPA-G. However, further investigation into these measures is needed using longer narrative elicitation tasks. Longer elicitation tasks

may result in more variation in the performance between the groups of each PPA variant. Also, while the test battery approach for subtyping PPA suggested by Mesulam and colleagues (2009) helps with subtyping PPA variants based on an individual's performance on tests of syntax and semantics, the present study suggests that including measures of fluency in the subtyping of PPA may provide additional clinical utility in the differential diagnosis of PPA variants.

While treatments for PPA are in experimental phases of research, identifying an individual's PPA variant provides useful information that could be used to guide treatment. For example, an individual with PPA-S could benefit from therapy focused on improving word retrieval abilities or using compensatory strategies to help prevent and circumvent communication breakdowns. Further research is needed to test the effectiveness of treatments in delaying the progressing of PPA through targeting specific deficits characteristic of each subtype.

Future Directions

A limitation of this study is that the Cookie Theft picture description was the only narrative available for all participant groups. Due to the nature of the picture description protocol, which consists of a simple drawing of a familiar scene, narratives were generally short and simple. With this task, a large amount of lexical diversity was not elicited. Measures tested, such as MATTR, may have utility in detecting impaired lexical diversity with the use of a more complex narrative task. Additionally, due to the simple elicitation protocol, participants in all groups were observed to use simple, present progressive syntax to describe the majority of the scene (e.g., "The boy is standing. The

stool is falling."). It is probable that sentence complexity was not found to be significant in this study because sentence complexity was only coded in sentences that contained embedded clauses, modifying clauses, and passive syntax. Due to the repetition of syntactic forms throughout the narratives, a significant amount of complex sentences was not produced by participants.

Further testing could compare the performance of these groups on various linguistic measures using complex picture description tasks, or story re-telling narrative tasks. With longer narratives it would be possible to test the efficacy of measures that could not be tested in the present study. One suggested measure is a measure of lexical diversity called the D measure (Malvern & Richards, 1997). This is proposed as a measure to quantify lexical diversity without the length of the narrative sample affecting the calculation. The D measure uses TTR values from random selections of a language sample to create a TTR curve with a D coefficient that represents overall lexical diversity (Malvern & Richards, 1997). Another suggested measure is a measure of syntactic ability used in the Thorne & Faroqi-Shah study (2016) is Developmental Sentence Scoring. This measure accounts not only for syntactic complexity, but also for grammatical accuracy and the use of function words. Since the use of articles and auxiliaries appeared to impact grammaticality within the narratives, measures more sensitive to these deficits, as opposed to higher level errors of syntax, may be beneficial in the early detection of PPA. Both of these measures can easily be derived from the CLAN program (MacWhinney, 2000), provided the narrative sample contains a minimum of 50 utterances.

It would also be useful to further investigate which linguistic measures could differentiate subtypes of PPA relative to AD. Since members of the PPA group had

heterogeneous language profiles due to the different characteristics of each PPA variant, comparing each PPA variant to AD could yield useful information for the differential diagnosis of PPA relative to AD.

Another potentially useful analysis would be a longitudinal analysis of these linguistic measures at various intervals throughout the progression of PPA. Tracking these changes over time could reveal if aspects of language that are impaired early on in the course of the disease continue to decline at a constant rate, or if changes in the progression of the disease coincide with variable rates of decline in specific linguistic skills. This information could be clinically useful in determining treatment targets that could delay the progression of linguistic impairments in PPA, specific to each PPA variant.

Conclusions

Overall, the findings of this study support the idea that there are linguistic measures that have a high clinical likelihood of differentiating individuals with PPA from healthy aging adults and adults with related neurodegenerative conditions with the use of a simple, brief picture description task. The main findings were that participants with PPA showed impaired performance on the following measures: words per minute, proportion of Correct Information Units, and the proportion of grammatical utterances. In addition, participants with PPA produced more errors in fluency, word retrieval, and total errors than control participants and participants with MCI, thus supporting the idea that language in PPA not only declines, but also deviates from the performance of individuals

without linguistic deficits. A pattern emerged in which the language of participants with MCI remained similar to that of control participants; however, language in AD was shown to be compromised in such a way that makes it difficult to differentiate from language in PPA without the use of additional cognitive testing.

This study also examined the efficacy of select linguistic measures in the differential diagnosis of PPA subtypes. Accounts for impairments of fluency and syntax in PPA-G were supported; however, no measures were shown to have utility in the differential diagnosis of PPA-L compared to PPA-S. While this study was able to find statistical significance for speech rate, idea density, MLU, and verbs per utterance, the small sizes of each subtype group were a limitation of the study. Additionally, although idea density was found as a potential measure to differentiate individuals with PPA-G from participants with other subtypes of the disease, it appears that idea density may be a measure that is impacted by syntax, rather than measuring only semantics. As suggested in Thorne & Faroqi-Shah's study (2016), further research is needed to determine the validity of idea density as a measure of lexical-semantics.

In summary, the findings from the present study suggest that brief elicitation tasks can contribute to the clinical classification of PPA and variants of PPA. While additional research is needed to test the validity of these measures and the proposed cut-off scores, this study contributes to the understanding of linguistic deficits in PPA, in addition to the deficits present within each subtype of PPA. It is apparent that many aspects of language are impaired in the connected speech of participants with PPA relative to controls and individuals with MCI: speech rate, speech fluency, the efficiency and accuracy of language (i.e., CIUs), word retrieval, and syntax. Further study of these measures is

necessary to evaluate their clinical utility in the differential diagnosis of PPA and in

guiding treatment for these conditions.

Appendix A
Cookie Theft Picture

Stimulus for the Cookie Theft picture description task from the Boston Diagnostic
Aphasia Examination (BDAE; Goodglass & Kaplan, 1983).
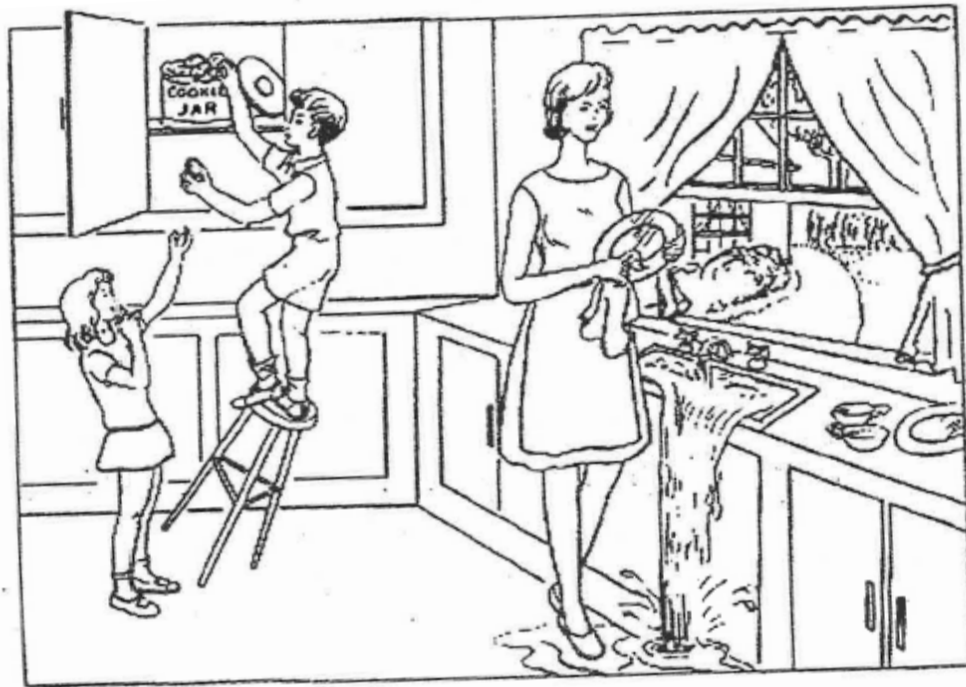
Appendix B
Operation definitions and Codes for CLAN Transcriptions

Definitions and codes were adapted from "A Clinician's Complete Guide to CLAN and PRAAT" manual available on http://childes.psy.cmu.edu/manuals/Clin-CLAN.pdf, as well as the "Coding Cheat Sheet" and "CHAT Error Coding for Aphasia" documents available on http://aphasia.talkbank.org/.

Fluency

Prolongation: : (colon after sound that is prolonged)
- Definition: Stretching out a sound or syllabic element.
- Example: s:paghetti

Phonological fragments related to word: & (use ampersand symbol attached to the graphemes that capture the sounds produced)
- Definition: Fragments of a word prior to the start of the target word. The same fragment is not repeated more than twice (if it is, use "repeated segments" code instead).
- Example: he had a &fr friend.
- Example: I really wanted to &v &vi visit the zoo.

Phonological fragments with change of word attempt: &+
- Definition: Change of word attempt. The sound fragment produced is not a sound in the target word.
- Example: I &+f wonder if it's a problem.

Repeated segments: ↩ (to create arrow, use "21AB" OR Hold "F2" and "/"; itierations inside of the sequence are marked with hyphens)
- Definition: A segment of the word is repeated multiple times (more than twice). This can occur at the beginning of a word or at the end of a word. If at the beginning of the word, unlike a phonological fragment, the sound is repeated more than once.
- Example: ↩r-r-r↩rabbit Repeated or like↩ike↩

Pauses: (.)
- Definition: Pauses that last longer than one second. This symbol isn't needed if the pause occurs between utterances.
- Example: it's like (.) a um (.) dog
  - Short, medium, and long pauses can be indicated with (.) (..) and (…) respectively

Filled Pauses: **&-**
- Definition: A pause filled with a word. The word used should be considered a disfluency, as opposed to a word that has communicative function
- Examples: &-um, &-you_know (multi-word fillers are connected with an underscore)

Word repetitions: [/]
- Definition: Whole word is repeated once.
- Example: butter [/] butter

Multiple whole word repetitions: [x N] (indicate number of repetitions in place of "N")
- Definition: Whole word is repeated more than once.
- Example: butter [x 7]

Phrase repetitions: <>[/]
- Definition: When the speaker repeats a phrase within a sentence without changing it at all.
- Example: <that is a> [/] that is a dog.

Phrase revisions: <>[//]
- Definition: When the speaker changes something (usually syntax) in an utterance but maintains the same idea.
- Example: <what did you> [//] how can you see it?

Word Retrieval

Word Level Errors:
- If the error is repeated, add "-rep" to the error code; if the error is revised (to another error or the correct word), add "-ret" to the code.
    - Example: the dog is in the tee [: tree] [* p:w] [/] tee [: tree] [* p:w-rep]. the dog is in the wee [: tree] [* p:w-ret] [//] tree .

Phonological paraphasia: [* p]
- Definition: For one-syllable words with an onset (initial phoneme/phonemes) and a vowel nucleus plus coda (final phoneme or phonemes), the error must match on 2 out of 3 of those elements. The part of the syllable with an error may be a substitution, addition, or omission. For multi-syllabic words, the error must have complete syllable matches on all but one syllable, and the syllable with an error must meet the one-syllable word match criteria previously mentioned.
- Specific error types include:
    - **[* p:w]**
        - Definition: Error is a real word that is phonologically similar to the target word.
        - Example: heat [: eat] [* p:w]
        - Example: cable [: table] [* p:w]
    - **[* p:n]**
        - Definition: Error is a non-word that is phonologically similar to the target word. Transcribe how the word sounds using IPA and attach @u to the error.
        - Example: peɪbl̩@u [: table] [* p:n]

Semantic paraphasia: [* s]
- Definition: A word that is related in meaning to the target word is used in place of the target word.
- Specific error types include:
    - **[* s:r]**
        - Definition: Error is a recognizable word that is semantically related to the target word
        - Example: fork [: knife] [* s:r]
        - Example: he [: she] [* s:r]
    - **[* s:uk]**
        - Definition: Error is a real word for which the target is unknown.
        - Example: and I go wolf [* s:uk]
    - **[* s:per]**
        - Definition: Repetition of a word when it is no longer appropriate.
        - Example: the boy kicked the ball through the ball [: window] [* s:per]

Mixed Paraphasia: [* sp:m]

- Definition: A word that contains both a semantic error and phonemic paraphasia. The word may be a real word that is related to the target word, but is also phonologically similar to it.
- Example: it was singing [: ringing] [* sp:m]

Neologisms: [* n]
- Definition: Non-words that do not meet the criteria for phonological or semantic errors. Transcribe how the word sounds using IPA and attach @u to the end of the word.
- Specific types include:
    - **[* n:k]**
        - Definition: Error is a non-word for which the target is known.
        - Example: she had all her gɹæstɪdʒɪz@u [: groceries] [* n:k].
    - **[* n:uk]**
        - Definition: Error is a non-word for which the target word is not known. Add [: x@n] as the target word after the error.
        - Example: I've only gone to two ɹɛsɪz@u [: x@n] [* n:uk] .
    - **[* n:k:s]**
        - Definition: Error is a recurring non-word for which the target is known.
    - **[* n:uk:s]**
        - Definition: Error is a recurring non-word for which the target is not known. Add [: x@n] as the target word after the error.

Circumlocutions: [+ cir]
- Definition: When the participant talks around words or concepts.

- Example: and through the help of <the whatever fairy or whoever the [x 3] what [//] the lady that is helping Cinderella &-um she has <the chance to check the> [//] the prince and check the &+s &-uh shoe . [+ cir]

Empty Speech: [+ es]
- Definition: Speech that has correct syntax, but that conveys little or no overall meaning. This is often due to the substitution of more general words (e.g., thing) for more specific words.
- Example: we got little things over here . [+ es]

Jargon: [+ jar]
- Definition: Mostly fluent and prosodically correct speech that is largely meaningless (with paraphasias, neologism, or unintelligible words). Resembles English syntax and inflection.
- Example: go and &ha hack [* s:uk] the gets [* s:uk] be able gable [* s:uk] get &+su sɪm@u [: x@n] [* n:uk] . [+ jar]

Semantic Content Error: [+ sce]
- Definition: A sentence that is grammatically correct, but which has an illogical meaning based on the picture prompt provided.
- Example: The boy is in the cookie jar . [+ sce]
  - The boy himself is not in the cookie jar, his hand is.

<div align="center">

Syntax

</div>

Morphological errors: [* m]
- Definition: Errors in changing a word form (e.g., adding a suffix to change words into plurals, past tense, possessives, etc.).
- Specific types include:
  - **[* m:a]**
    - Definition: Error in agreement
    - Example: and then she have [: has] [* m:a] two &-uh cups.
    - More specific errors in agreement include:
      - **[* m:a:0es]**
        - Definition: Missing 3rd person singular –s suffix
        - Example: the boy kick [: kicks] [* m:a:0es] the ball
      - **[* m:a:+es]**
        - Definition: Superfluous 3rd person singular agreement error
        - Example: we goes [: go] [* m:a:+es]
      - **[* m:a:0s]**
        - Definition: Missing plural on noun
        - Example: two sister [: sisters] [* m:a:0s]
      - **[* m:a:+s]**
        - Definition: Superfluous plural on nouns.

- Example: one dogs [: dog] [* m:a:+s]
- **[* m:c]**
  - Definition: Error in case
  - Example: hers [: her] [* m:c] father is trying to get the cat.
- Other errors include:
  - **[* m:0s]**
    - Definition: Missing –s suffix, including irregulars
    - Example:
  - **[* m:0's]**
    - Definition: Missing possessive –s suffix
    - Example: the boy [: boy's] [* m:0's] dog
  - **[* m:=s]**
    - Definition: Over-regularized –s
    - Example: her pets and her childs [:: children] [* m:=s] are outside.
  - **[* m:+s]**
    - Definition: Superfluous –s suffix
    - Example: Feets [: feet] [* m:+s]
  - **[* m:++s]**
    - Definition: Double –s used.
    - Example: kniveses [: knives] [*m:++s]
  - **[* m:0ing]**
    - Definition: Missing progressive –ing suffix.
    - Example: she is clean [: cleaning] [* m:0ing] the plates.
  - **[* m:+ing]**
    - Definition: Superfluous progressive –ing suffix used.
    - Example: they need to going [: go] [* m:+ing] to the store .
  - **[* m:0ed]**
    - Definition: Missing past –ed suffix
    - Example: he got a ladder and he climb [: climbed] [* m:0ed] up the tree.
  - **[* m:=ed]**
    - Definition: Over-regularized –ed past tense form used.
    - Example: He seed [: saw] [* m:=ed] the cookie.
  - **[* m:+ed]**
    - Definition: Superfluous past tense used
    - Example: we want to walked [: walk] [* m:+ ed] to the store.

Formal lexical device errors: [* f]
- Definition: Lexical device used is incorrect, not just incorrectly conjugated.
  - **[* f:p]**

- ▪ Definition: part of speech used in incorrect; also part of speech errors involving derivations, as in "assess" for "assessment".
- ▪ Example: my [: mine] [* f:p] is taller than yours.

Missing word errors: 0 (+missing word or part of speech)
- Definition: Words that are missing from the utterance.
- Example: the boy climb on 0det stool. (missing determiner/article "the")
- Example: he 0aux falling. (missing auxiliary "is")

Grammatical error: [+ gram]
- Definition: Utterances in which necessary grammatical elements (e.g., subjects, verbs, auxiliaries, prepositions) are missing or incorrectly used, with the exception of appropriate one word answers to questions or to other appropriate one word communicators (e.g., yes, mhm). Also refers to utterances with errors in word order, syntax, or grammatical morphology.
- Example: they were knowing them and they didn't know what was going on either too. [+ gram]

Sentence Complexity: [+ comp]
- Definition: Sentence complexity should be marked in a sentence if it contains:
  - o Embedded clauses, where a subject and a verb are within the main clause (i.e., there will be at least two verbs in the sentence). These often begin with wh- words including who, which, where, while, and that.
    - ▪ Example: The cookie jar, which is on the shelf, is falling. [+ comp]
  - o Modifiers that add detail to the sentence. These often begin with wh- words including who, which, where, while, and that.
    - ▪ Example: The boy climbed up on a stool that is tilting.
  - o Passive sentences where the subject of the sentence has an action done to it by someone or something else
    - ▪ Example: The cookie jar was stolen by the boy. [+ comp]
  - o *Note*: conjunctions alone do not make a sentence complex

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