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Investigating the Impact of Nonlinguistic Cognitive Reserve on Naming Pre- And Post-treatment

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INVESTIGATING THE IMPACT OF NONLINGUISTIC COGNITIVE RESERVE ON NAMING PRE- AND POST-TREATMENT

by

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DEDICATION

To Mom and Dad for always inspiring my love of learning, and to Mom, Dad, and Adam for all your love and encouragement. I am lucky to have you in my life, and it means a great deal to me to know that I always have your support.

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ABSTRACT

Background: The relationship between linguistic and nonlinguistic cognition in persons with aphasia is complex and often debated in the literature. Furthermore, the impact of nonlinguistic cognition on aphasia treatment outcomes is unclear. The present study sought 1) to examine the relationship between WAIS scores and performance on a test of naming and 2) to examine the relationship between WAIS scores and change scores on a test of naming between baseline and post-treatment in persons with chronic aphasia.

Method: This retrospective study utilized data from participants (N=102) who were recruited for a multi-center cross-over trial (POLAR: Predicting Outcomes of Language Rehabilitation). Data from the POLAR behavioral test battery were analyzed including: PNT, WAIS Matrix Reasoning, and WAB-R. Six multiple linear regression models were created to examine the effects of nonlinguistic cognition on baseline naming performance and error type. An additional 6 multiple linear regression models were created to examine the effects of nonlinguistic cognition on changes in naming performance and error type. For a subset of participants (N=69), WAIS Matrix Reasoning scores were classified by test items that could be solved by visual pattern-matching or relational reasoning to further investigate the effect of nonlinguistic cognitive reserve.

Results: Consistent with the literature, WAB AQ and age at testing were the most consistent predictors of baseline and post-treatment naming performance. WAIS Matrix Reasoning scores did not predict baseline naming performance or post-treatment naming

change scores. However, the effects of relational reasoning test items trended toward statistical significance for post-treatment naming change scores.

Conclusions: The relationship between linguistic and nonlinguistic cognition is complex and difficult to investigate in isolation. From this study there is limited evidence to suggest that nonlinguistic cognition is associated with measures of naming, nor does it greatly impact treatment-related naming gains. Future research should examine the impact of other aspects of nonlinguistic cognition, such as attention and working memory, on aphasia treatment response.

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LIST OF ABBREVIATIONS

AQ.. Aphasia Quotient

ASHA..American Speech-Language-Hearing Association

BNT.. Boston Naming Test

CLQT ....Cognitive-Linguistic Quick Test

CVA ....Cerebrovascular Accident

PNT ....Philadelphia Naming Test

POLAR .... Predicting Outcomes of Language Recovery

PWA.. Person with Aphasia

RCPM ....Raven's Coloured Progressive Matrices

RR .... Relational Reasoning

SLT ....Speech-Language Therapy

VPM.. Visual Pattern-Matching

WAB-R .... Western Aphasia Battery-Revised

WAIS ....Wechsler Adult Intelligence Scale

WCST .... Wisconsin Card Sorting Test

CHAPTER 1

BACKGROUND

Aphasia is an acquired language disorder that can impact all aspects of a person's ability to communicate in everyday life. It can impact language across all communication modalities, including speaking, reading, writing, and comprehending speech. In addition to affecting everyday communication, aphasia can have drastic effects on a person's quality of life (Ross et al., 2010; Hilari, 2011). Aphasia severity can vary widely and is highly dependent on the size and location of lesion damage (Fridriksson et al., 2016, Fridriksson et al., 2018). While the symptoms each person with aphasia (PWA) experiences are also heterogeneous (Fridriksson et al., 2018), aphasia is commonly subdivided into 'types' based on behavioral symptoms (verbal fluency, comprehension, and repetition ability). Goodglass & Kaplan (1972) describe the following aphasia subtypes: global aphasia, mixed transcortical aphasia, Broca's aphasia, transcortical motor aphasia, Wernicke's aphasia, transcortical sensory aphasia, conduction aphasia, and anomic aphasia. These subtype criteria are specific to observed language impairments, and it is widely accepted that aphasia specifically impacts language, not cognition, regardless of aphasia type.

Behavioral speech-language therapy (SLT) remains the most common approach to aphasia rehabilitation. There are two main approaches to behavioral SLT: impairment-based approaches and functional communication approaches. Impairment-based

approaches aim to improve language functioning by targeting specific language components. Functional communication approaches focus on compensating for language deficits and improving overall communication success. Despite a wealth of treatment options, the efficacy of aphasia therapy was debated until relatively recently, and it is still unclear which treatments work best for patients with different aphasia profiles (Fridriksson & Hillis, 2021). However, recent meta-analyses support the position that SLT is beneficial for PWAs (Brady et al., 2016). Furthermore, Breitenstein et al. (2017) provide evidence for the efficacy of impairment-based SLT in a recent Phase III randomized controlled trial. The results of this trial demonstrate that SLT improves verbal communication in people with chronic aphasia as well as improves communicative quality of life (Breitenstein et al., 2017).

As demonstrated in the literature, there is increasing evidence for the efficacy of SLT. However, predicting which patients will respond to a given intervention continues to challenge clinicians treating PWA (Fridriksson & Hillis, 2021). Factors including age, education, nonlinguistic cognitive ability, social status, health, and time post-stroke have been suggested as biographical predictors of aphasia recovery (Darley, 1972; Johnson et al., (accepted, Cortex)). More recently, research has also indicated effects of neurobiological predictors on aphasia recovery, including lesion volume, lesion location, and leukoaraiosis severity (Johnson et al., 2022; Basilakos et al., 2019; Wilmskoetter et al., 2019). Of particular interest for this study is the impact of nonlinguistic cognition on aphasia treatment outcomes. While aphasia is a language disorder, the extent to which other cognitive processes impact aphasia treatment and recovery is still highly debated.

Cognition is a complex process often defined as having five primary domains: attention, executive functions, language, memory, and visuo-spatial skills (Helm-Estabrooks, 2002). As with language, each nonlinguistic cognitive domain can be further subdivided into more specific components. Attention can be separated into sustained, selective, and divided attention (Papathanasiou & Coppens, 2017). Without the ability to attend to a given task, higher-level information processing cannot occur, so it is often considered a requisite skill for other cognitive domains (Helm-Estabrooks, 2002). Executive functioning encompasses higher-level cognitive skills necessary for planning, organizing, shifting, sequencing, problem-solving, and goal-oriented behavior (Mueller & Dollaghan, 2013). Types of memory are differentiated based on storage capacity and duration (Papathanasiou & Coppens, 2017). Short-term memory might last only seconds, whereas long-term memory might last a lifetime (Papathanasiou & Coppens, 2017). Long-term memory can also be further subdivided into declarative or explicit memory (e.g., memories of facts or events) and non-declarative or procedural memory (e.g., skill-based memories). Finally, visuo-spatial skills include the perception of depth, distance, and shape; localization; and identifying relationships between objects (Joseph, 1988).

Recently, the broader stroke literature has discussed a relationship between cognitive reserve and stroke-related impairments. Evidence from previous studies suggests that cognitive reserve is a significant factor in stroke recovery and language deficits (Rosenich et al., 2020). ‘Reserve’ refers to a feature of the brain’s structure and function that is thought to regulate the clinical expression of brain pathology or injury (Stern, 2002). Cognitive reserve is an active process and consists of two features: neural reserve and compensation (Stern, 2002). These features may aid in 1) optimizing or

strengthening existing, effective processing strategies when neural networks are damaged and 2) recruiting alternate neural networks to compensate for damaged neural networks (Stern, 2002). Complex mental or lifestyle activities (e.g., years of education, cognitive activity, and social activity) are thought to improve the development of cognitive reserve (Rosenich et al., 2020).

Some researchers propose that all cognitive domains are involved in the aphasia rehabilitation process (Helm-Estabrooks, 2002), and language processing involves integrating linguistic and nonlinguistic cognitive abilities (Peach, 2017). Cognitive performance factors, specifically misallocated nonlinguistic cognitive resources, have been discussed as a potential cause of language impairment following post-stroke aphasia (McNeil et al., 1991). There is also an argument that underlying cognitive deficits can explain variable aphasia treatment responses (Sinotte & Coelho, 2007).

Nevertheless, traditional aphasia rehabilitation centers on which language functions are impaired or spared (Helm-Estabrooks, 2002). While there is still debate in the literature as to the involvement of cognitive processes in aphasia rehabilitation, research has shown that nonlinguistic cognitive impairments often co-occur with aphasia (El Hachioui et al., 2014). This relationship could be an age-related effect because PWA are often older adults who have lower baseline cognitive ability than younger adults (Salthouse, 2009). However, identifying concomitant cognitive deficits is, nevertheless, an important part of aphasia rehabilitation as such impairments might prevent successful language rehabilitation (Papathanasiou & Coppens, 2017). Unfortunately, identifying cognitive deficits requires neuropsychological assessment, and many neuropsychological

tests have linguistic demands, making them inappropriate for use with PWAs (Helm-Estabrooks, 2002).

Studies investigating the impact of cognition in PWA usually employ nonlinguistic cognitive tests. A study by Basso et al. (1973) used the Raven's Coloured Progressive Matrices (RCPM; Raven, 1965) as part of their study's test battery. The RCPM is a nonverbal assessment of visual analogic thinking consisting of a series of visual matrices each with a missing piece. For each test item, test-takers must select the piece that best completes the visual matrix from an array of six options. Participants (N=159) with unilateral brain damage were administered the RCPM as well as assessments of language, cognition, and visuo-spatial processing. Participants were subdivided by the hemispheric site of the lesion as well as the presence or absence of aphasia and visual-field deficits. While left-hemisphere-damaged participants with aphasia were significantly impaired on the RCPM, Basso et al. (1973) found no significant correlation between RCPM scores and scores earned on tests of naming and oral comprehension by participants with left-hemisphere damage, aphasia, and no visual-field deficits. This study also found that participants with right-hemisphere damage who had visual-field deficits were also significantly impaired, and participants with damage to either hemisphere scored significantly lower than controls. Basso et al. (1973) suggest that their results can be explained by considering lesion location, specifically areas critical to intelligence that overlap with areas critical for visual processing and language.

A study by Helm-Estabrooks (2002) sought to describe the relationship between linguistic and nonlinguistic cognitive skills (attention, executive function, memory, and visuo-spatial processing) in 13 PWAs. This study utilized four linguistic subtests

(Personal Facts, Confrontation Naming, Story Retelling and Paragraph Comprehension, and Generative Naming) and four subtests targeting nonlinguistic cognition (Symbol Cancellation, Alternating Symbol Trails, Memory for Designs, and Mazes) from the Cognitive-Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001). Results of this study found no significant relationship between linguistic and nonlinguistic cognitive skills, suggesting a dissociation between nonlinguistic and linguistic cognitive ability.

In a study examining the role of language in reasoning and problem-solving, Baldo et al. (2005) found correlations between core language processes (comprehension and naming) and problem-solving performance. This study tested 41 stroke survivors (31 had a left-hemisphere cerebrovascular accident (CVA)) on a battery of tests targeting language, problem-solving, and visuo-spatial skills. Testing included the Western Aphasia Battery, RCPM, and Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtis, 1993) as their main measures of interest. The WCST is a well-established assessment of problem-solving that requires participants to sort cards into piles based on color, shape, and number. Their results showed that the WCST and RCPM correlated with language performance, and more severe language impairment correlated with reduced problem-solving ability (Baldo et al., 2005). They argue from these results that higher-level problem solving involves linguistic support (Baldo et al., 2005).

In a follow-up study, Baldo et al. (2015) examined the relationship between aphasia severity and reasoning using another common assessment of linguistic and nonlinguistic cognitive skills, the Wechsler Assessment Intelligence Scale (WAIS; Wechsler, 2008). Specifically, Baldo et al. used the Picture Completion and Picture Arrangement subtests of the WAIS-R and WAIS-III, this time in a larger sample of

participants with left hemisphere CVAs only. These tasks were selected to differentiate required levels of reasoning, with Picture Arrangement serving as the more reasoning-intensive task (Baldo et al., 2015). 37 Participants with aphasia and 23 controls were tested. An analysis of covariance revealed that PWAs performed significantly poorer than controls on the Picture Arrangement task but were not statistically different on the Picture Completion task (Baldo et al., 2015). The authors argue that language impairment relates to poorer performance on tasks that require increased reasoning ability (Baldo et al., 2015).

Baldo et al. (2010) devised a behavioral and neuroimaging study examining PWAs' (N=107) performance on the RCPM with the position that linguistic abilities are necessary for complex problem solving. They categorized RCPM test items, *a priori*, by how the solution is derived, either by visual pattern-matching (VPM) or relational reasoning (RR). Of the 36 RCPM test items, 17 were classified as VPM and ten were classified as RR. Study results showed that PWAs had significant impairment on the RR condition relative to control participants (Baldo et al., 2010). While sample sizes for some aphasia subtypes, classified using WAB AQ, were too small for statistical analysis, behavioral results from this study suggested an effect of aphasia subtype outside of aphasia severity on RCPM performance (Baldo et al., 2010). Participants with more severe forms of aphasia (e.g., Broca's, Wernicke's, and global) showed the greatest inconsistency between conditions (Baldo et al., 2010). However, their poorer performance was not uniform between conditions, as those with Broca's aphasia scored relatively well on the VPM condition while showing poorer performance on the RR condition (Baldo et al., 2010). These results indicate that PWAs showed greater

impairment, particularly on test items requiring relational reasoning, providing additional evidence for the role of language in higher-level reasoning and problem-solving (Baldo et al., 2010).

Taken together, these studies have sought to disentangle linguistic and cognitive processes, which has led to disparate findings, leaving room for more questions. Additionally, few studies have directly examined the relationship between nonlinguistic cognitive abilities and aphasia treatment outcomes. Dignam et al. (2017) conducted a study of 32 PWAs investigating the impact of language and cognitive abilities on anomia therapy outcomes. Their assessment battery included tests for language, attention, verbal memory and learning, visuo-spatial memory and learning, and executive function. Findings from this study suggest that cognitive and linguistic ability at baseline impact naming gains following aphasia therapy (Dignam et al., 2017). Specifically, Dignam et al. (2017) found a positive effect on naming from verbal short-term memory and lexical-semantic processing. However, these results were obtained using a relatively small sample size (N=32). Furthermore, while participants received 48 hours of total therapy, only 14 hours of that was impairment-based (Dignam et al., 2017).

Gilmore et al. (2019) examined whether nonlinguistic cognitive abilities at baseline predicted language treatment outcomes. The first of two studies included data from 67 PWAs, and participants underwent an extensive pre-treatment cognitive-linguistic assessment battery (Gilmore et al., 2019). A principal component analysis revealed two distinct components corresponding to linguistic and nonlinguistic cognition. Assessments corresponding to the linguistic component included all subscales of the Western Aphasia Battery-Revised (WAB-R), CLQT subtests measuring linguistic

processing, the Boston Naming Test, and the Pyramids and Palm Trees Test. Assessments corresponding to the nonlinguistic cognition component included WAB-R reasoning and problem-solving subscales, CLQT subtests measuring nonlinguistic cognition, and the Pyramids and Palm Trees Test. Study 1 found that pretreatment nonlinguistic cognitive skills had a greater impact on naming treatment than sentence comprehension treatment. The second of the two studies included data from 27 PWAs who had completed additional pre-treatment cognitive testing (Gilmore et al., 2019). The results of Study 2 indicated that executive function and visual short-term memory impacted immediate semantic-based treatment gains and longer-term maintenance of treatment gains.

If extralinguistic cognition affects language recovery and treatment response, as has been shown in previous research, it is still unclear at what levels language and cognitive processing interact. It is also still unclear to which extent nonlinguistic cognition impacts aphasia rehabilitation outcomes. The current study aims to add to previous findings by examining the impact of nonlinguistic cognitive reserve on naming treatment outcomes. Additionally, this study will examine error use pre- and post-treatment, which has not been a feature of previous studies and motivates this study further.

CHAPTER 2

AIMS

The purpose of the present study was to address the extent to which nonlinguistic cognitive reserve influences language rehabilitation outcomes for persons with post-stroke aphasia. A retrospective analysis of data from the POLAR study was conducted to address the following two aims:

Aim 1: To examine the relationship between WAIS scores and performance on a test of naming.

The first aim serves to investigate the impact nonlinguistic cognitive reserve has on baseline performance on tests of naming and aphasia severity. It also serves as a basis for comparison for Aim 2.

Hypotheses

It is predicted that there will not be a relationship between overall WAIS scores and baseline naming performance on the PNT. However, the relationship will be a function of error type. It is predicted that there will not be a relationship between WAIS scores and phonemic errors, but there will be a relationship between WAIS scores and semantic errors. Specifically, participants with higher WAIS scores will demonstrate fewer semantic errors.

The PNT is a test of lexical access, which is primarily a language skill. In a principal component analysis, Gilmore et al. (2019) found that scores on the Boston Naming Test (BNT) loaded on the language component but not the cognitive component. As the PNT and BNT are both naming assessments, it follows that baseline cognitive reserve will have a limited impact on a participant's overall score on the PNT. In their study, Gilmore et al. (2019) also found that the Pyramids and Palm Trees Test loaded on both the language and cognitive components as this assessment measures both conceptual reasoning and semantic access, measures of nonlinguistic and linguistic cognition, respectively. With this apparent connection between conceptual reasoning and semantic access, there could be a closer relationship between WAIS scores and the number of semantic errors participants make.

Aim 2: To examine the relationship between WAIS scores and change scores on a test of naming between baseline and post-treatment.

The second aim investigates the involvement of nonlinguistic cognitive reserve on aphasia treatment outcomes immediately post-treatment. Specifically, this aim examines PNT change scores, including changes in the number and type of errors made.

Hypotheses

It is predicted that there will be a relationship between WAIS scores and improvements in naming performance. As for PNT error type, it is predicted that higher WAIS scores will result in a reduction of semantic errors as this error type involves the integration of linguistic and nonlinguistic skills to a greater degree.

It is proposed that improvements in naming performance involve some degree of learning ability. WAIS scores serve as a measure of nonlinguistic cognitive reserve, which is expected to support learning in PWAs receiving aphasia therapy. Previous evidence suggests that there is a relationship between baseline cognitive reserve and improvement in naming following behavioral language therapy (see Gilmore et al., 2019).

CHAPTER 3

METHODS

Participants

The present retrospective study utilized data from a multi-center cross-over trial (POLAR). The aims of POLAR were to investigate who responds to speech and language therapy and the degree to which participants respond to therapy. Participants were recruited via the University of South Carolina (USC) and Medical University of South Carolina (MUSC) from 2015 to 2020. Participants were included if they were in the chronic stage of aphasia (≥ 12 months post-stroke) resulting from a left-hemisphere stroke (ischemic or hemorrhagic). Other POLAR inclusion criteria are as follows: age (21-80 years), primary language (English), ability and willingness to provide written and verbal consent, and MRI eligibility. Participants were excluded under the following conditions: severely limited auditory comprehension (WAB-R Comprehension score of 0-1) or severely limited verbal output (WAB-R Spontaneous Speech score of 0-1). Participants who met the inclusion criteria participated in baseline testing, two rounds of speech-language therapy, and outcome assessments immediately post-treatment as well as at 1-month, 6-month, and 1-year timepoints following therapy completion. 127 participants were enrolled in the POLAR study, including 20 control participants without aphasia, who only underwent baseline testing. 107 participants underwent therapy. Of those participants, five participants withdrew their study consent resulting in 102 participants who completed all therapy protocols. Relevant participant demographic

information is described in Table 3.1. For further information on POLAR participants, see Kristinsson et al. (2021).

Table 3.1 Participant Summary (N=102)

	Mean (SD)	***Range***
WAB AQ	59.95 (22.7)	14.5-95.4
Test Age	60.51 (10.89)	29-80
WAIS Scores	11.84 (5.74)	3-22
Baseline PNT Scores	79.76 (60.93)	0-172

Testing

Upon enrollment in the POLAR study, biographical data were obtained for each participant using a detailed case history form and questionnaire. A baseline interview was also conducted by an American Speech-Language-Hearing Association (ASHA)-certified SLP to clarify information or gather additional biographical data, as needed.

Participants underwent an extensive neuropsychological test battery at baseline and subsequent testing points, which included speech, language, and nonverbal cognitive testing. Tests were administered by ASHA-certified SLPs in keeping with the administration and scoring instructions provided in each testing manual. A Clinical Core team implemented an assessment fidelity and reliability program. See Spell et al. (2020) for the full POLAR fidelity protocol.

The neuropsychological tests incorporated as potential predictors of therapy response in the current study are described in detail below.

Philadelphia Naming Test (PNT; Roach et al., 1996). The PNT is a computerized picture-naming task designed to measure lexical access in aphasic and non-aphasic speakers. It consists of 175 high- and medium-frequency nouns varying in length from 1-4 syllables. During the test, participants are instructed to name each picture when it appears on the computer screen. Each naming trial ends after one of the following conditions: an overt response or after 30 seconds have elapsed. Higher scores indicate greater preservation of naming skills.

Wechsler Adult Intelligence Scale-Matrix Reasoning (WAIS; Wechsler, 2008). The WAIS is a clinical instrument used to assess intellectual ability. It consists of several subtests, which each measure a different aspect of intelligence. The Matrix Reasoning subtest measures visual information processing and abstract reasoning skills. It consists of 26 items which fall under one of four types: (i) continuous and discrete pattern completion, (ii) classification, (iii) analogy reasoning, and (iv) serial reasoning. For the purposes of this study, WAIS Matrix Reasoning scores serve as a measure of nonlinguistic cognitive reserve.

Western Aphasia Battery-Revised (WAB-R; Kertesz, 2007). The WAB-R assesses overall language impairment and classifies the type and severity of aphasia (if present). The assessment includes tests of several functional domains which are represented as scores on the following subtests: Spontaneous Speech (speech content and fluency of speech), Auditory Comprehension, Speech Repetition, and Naming. The subtest scores contribute to the Aphasia Quotient (AQ), which is an overall measure of aphasia severity. Across all WAB-R subtests, a higher score indicates less severe impairment.

Statistical Analysis

Aim 1

Six multiple linear regression models were created to address Aim 1. The first three models used data from the 102 participants who completed all POLAR therapy protocols. Model 1 examined baseline PNT scores, Model 2 examined the number of baseline PNT phonemic errors, and Model 3 examined the number of baseline PNT semantically related errors each with the following independent variables: WAIS Matrix Reasoning scores, WAB AQ scores, and age at testing. All variables were correlated (Pearson) to investigate potential multicollinearity.

The following three models addressing Aim 1 used data from a subset of participants (N=69), summarized in Table 3.2. The number of participants in this second subset (N=69) of models (Models 4 through 6) consists of participants who had itemized WAIS matrix reasoning scores and had answered up to at least item 12 out of 29 (including the 3 practice items) on the WAIS Matrix Reasoning subtest. WAIS testing discontinues after a certain criterion for each subtest, therefore not all participants receive all items. The Matrix Reasoning subtest discontinues after four consecutive scores of 0 or after four scores of 0 out of five consecutive questions. For the present study, WAIS Matrix Reasoning scores were categorized into visual pattern-matching (VPM) and relational reasoning (RR), as done by Baldo et al. (2010). See Fig. 3.1 for an example of VPM and Fig. 3.2 for an example of RR. This cut-off point, Matrix Reasoning item 12, was selected as it includes at least five RR test items. Due to the WAIS Matrix Reasoning discontinuation rule, there was no guarantee that participants would have had the opportunity to attempt a RR test item because they occur predominantly in the second

half of the Matrix Reasoning subtest. Not attempting a question is not equivalent to an incorrect response. Therefore, this cut-off point was selected to ensure participants had attempted a minimum number of 5 RR test items.

Table 3.2 Participant Summary (N=69)

	Mean (SD)	***Range***
WAB AQ	59.95 (22.7)	14.5-95.4
Test Age	60.51 (10.89)	29-80
WAIS Scores	11.84 (5.74)	3-22
Baseline PNT Scores	79.76 (60.93)	0-172

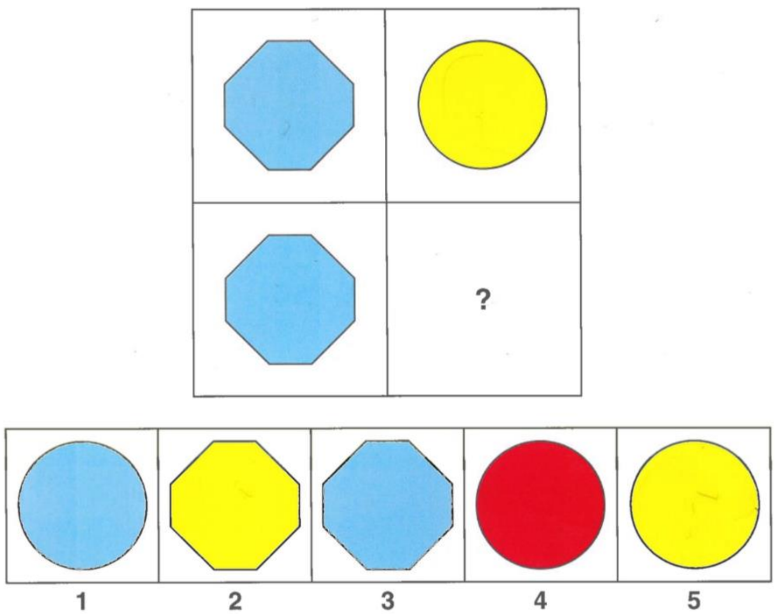

Figure 3.1 WAIS Visual Pattern-Matching

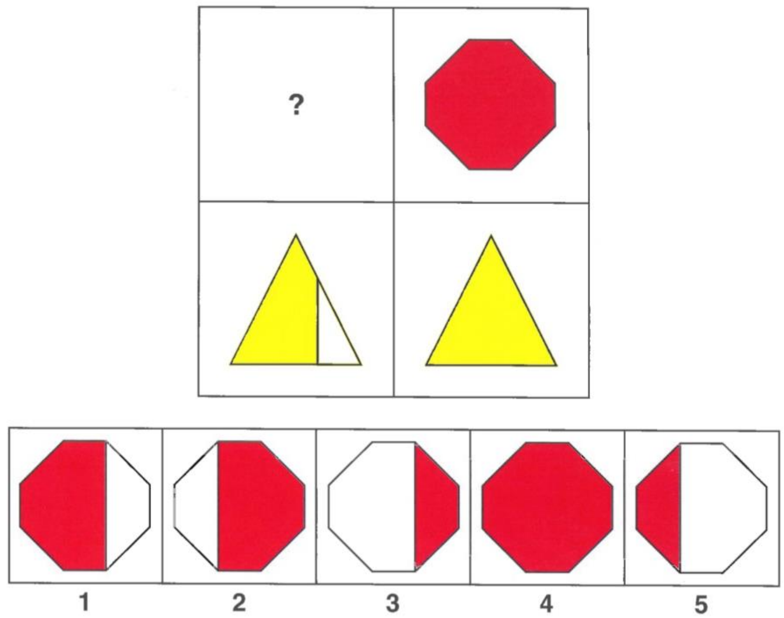

Figure 3.2 WAIS Relational Reasoning

Models 4-6 examined the same three dependent variables as the first three models. However, the factors of interest for these models were slightly modified and included VPM ratio correct, RR ratio correct, WAB AQ, and age at testing. VPM and RR ratio correct scores were calculated for each participant by taking the number of each question type participants answered correctly and dividing that by the number of each question type participants were exposed to.

WAIS Matrix Reasoning, like the RCPM, measures non-verbal reasoning. In these tests, individuals must determine which of several alternatives best completes a visual pattern. Some test items require relational reasoning, which entails the ability to recognize and integrate two or more dimensions of relational change (Christoff et al., 2001). Other test items can be solved only via visual pattern-matching (DeShon, Chan, & Weissbein, 1995). For the purposes of this study, the author categorized each WAIS Matrix Reasoning test item, *a priori*, as either VPM or RR. The categorizations were discussed with Committee Member (LJN). Consensus was reached on all but three test

items (7, 10, and 18), therefore Thesis Director (DdO) provided a third rating and item classifications were assigned based on majority agreement.

Aim 2

To address this aim, six additional models were created. The first set of three models (Models 7 through 9) again included data from the full set of participants (N=102). The independent variables were WAIS Matrix Reasoning scores, WAB AQ scores, and age at testing, and the dependent variables were overall PNT change scores, change in phonemic errors, and change in semantic errors. Change scores were calculated from PNT scores (raw total correct, number of semantic errors, and number of phonological errors) immediately post-treatment and at baseline. These scores were then used as the dependent variables in the models.

The second set of three models (Models 10 through 12) used data from the same subset of participants (N=69). The independent variables were VPM ratio correct, RR ratio correct, WAB AQ scores, and age at testing, and the dependent variables were overall PNT change scores, change in phonemic errors, and change in semantic errors. All statistical analyses were done using statistical software R, and figures were made using package GGPLOT2 in R.

CHAPTER 4

RESULTS

Six models were created to address Aim 1 and six models were created to address Aim 2. Table 3.1 provides a summary of demographic information for the participants (N=102) included in Models 1-3 and 7-9. Table 3.2 provides a summary of demographic information for the participants (N=69) included in Models 4-6 and 10-12.

Aim 1 – Baseline Models

Six baseline models were created to investigate what factors predict 1) Baseline total PNT correct, 2) Baseline phonological errors, and 3) Baseline semantic errors. The first set of models used data from all participants (N=102), and the second set of models used data from a subset of those participants (N=69). See Table 4.1 for a complete list of formulas used for each model. Independent variables included in the first set of three models were WAIS Matrix Reasoning scores, WAB AQ, and age at testing, while independent variables for the second set of three models were visual pattern-matching (VPM) ratio correct, relational reasoning (RR) ratio correct, WAB AQ, and age at testing. Fig. 4.1 presents the (Pearson) correlation matrix between all independent variables. A significance value of 0.05 was selected for all models.

Table 4.1 Model Formulas for Aims 1 and 2

Aim 1

	Model	Formula
N = 102	1	PNT Baseline Total ~ WAIS Total + WAB AQ + Test Age
	2	PNT Baseline Phon Errors ~ WAIS Total + WAB AQ + Test Age
	3	PNT Baseline Sem Errors ~ WAIS Total + WAB AQ + Test Age
N = 69	4	PNT Baseline Total ~ VPM Ratio Correct + RR Ratio Correct + WAB AQ + Test Age
	5	PNT Baseline Phon Errors ~ VPM Ratio Correct + RR Ratio Correct + WAB AQ + Test Age
	6	PNT Baseline Sem Errors ~ VPM Ratio Correct + RR Ratio Correct + WAB AQ + Test Age

Aim 2

	Model	Formula
N = 102	7	Δ PNT Total ~ WAIS Total + WAB AQ + Test Age
	8	Δ PNT Phon Errors ~ WAIS Total + WAB AQ + Test Age
	9	Δ PNT Sem Errors ~ WAIS Total + WAB AQ + Test Age
N = 69	10	Δ PNT Total ~ VPM Ratio Correct + RR Ratio Correct + WAB AQ + Test Age
	11	Δ PNT Phon Errors ~ VPM Ratio Correct + RR Ratio Correct + WAB AQ + Test Age
	12	Δ PNT Sem Errors ~ VPM Ratio Correct + RR Ratio Correct + WAB AQ + Test Age

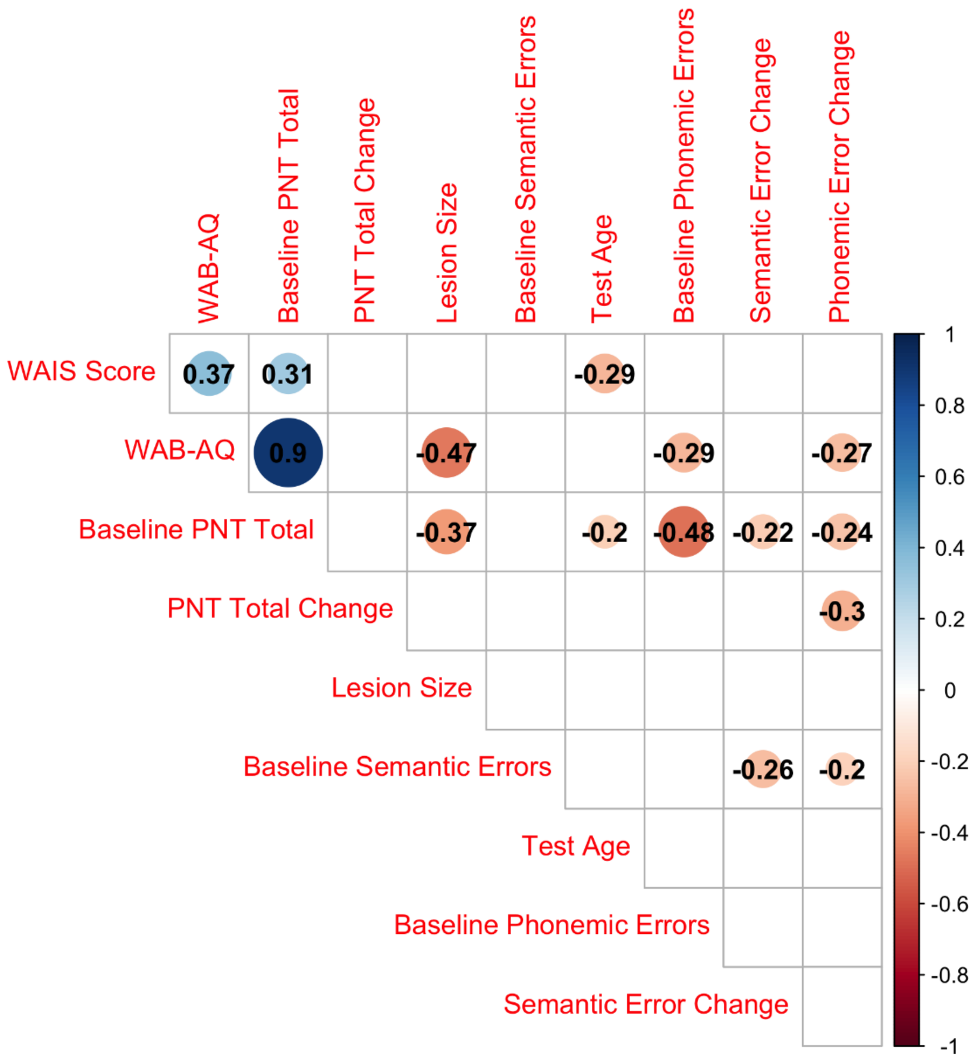

Figure 4.1 Correlation Matrix of Independent Variables

Two statistically significant main effects (WAB AQ and age at testing) were revealed from Model 1, illustrated in Fig. 4.2 and Fig. 4.3, indicating a positive relationship between aphasia severity (β=2.44; p< 0.00001) and baseline PNT scores and a negative relationship between age at testing (β=-0.62; p=0.014) and baseline PNT scores. WAIS Matrix Reasoning scores did not significantly predict participants' overall PNT scores at baseline. Model 2 revealed two statistically significant main effects (WAB AQ and age at testing), illustrated in Fig. 4.4 and Fig. 4.5, indicating a negative relationship between aphasia severity (β=-0.14; p=0.004) and baseline phonemic errors

and a positive relationship between age at testing (β=0.16; *p*=0.09) and the number of baseline phonemic errors. Again, WAIS Matrix Reasoning scores were not a significant predictor of baseline PNT phonemic errors. No significant values were revealed from Model 3, indicating no relationship between WAIS Matrix Reasoning scores, aphasia severity, or age at testing on baseline semantic errors. Table 4.2 lists a full summary of the linear regression model results for Models 1-3.

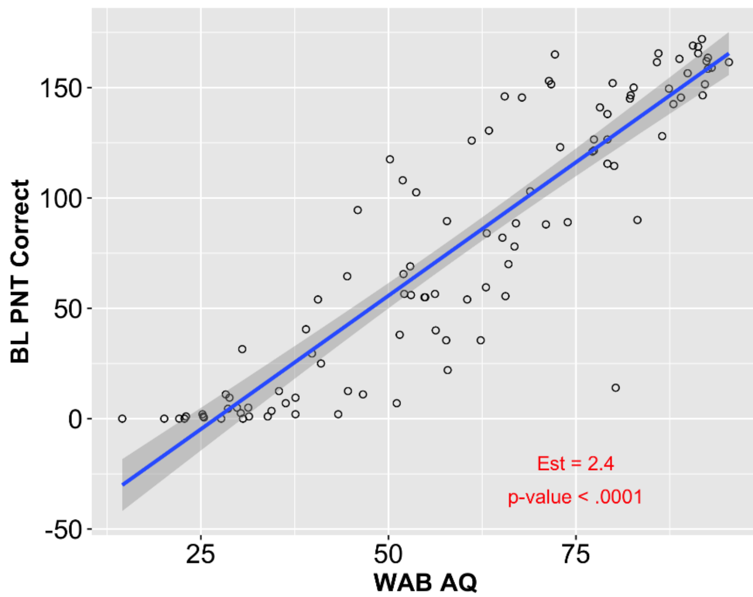

Figure 4.2 WAB AQ and PNT Baseline Scores

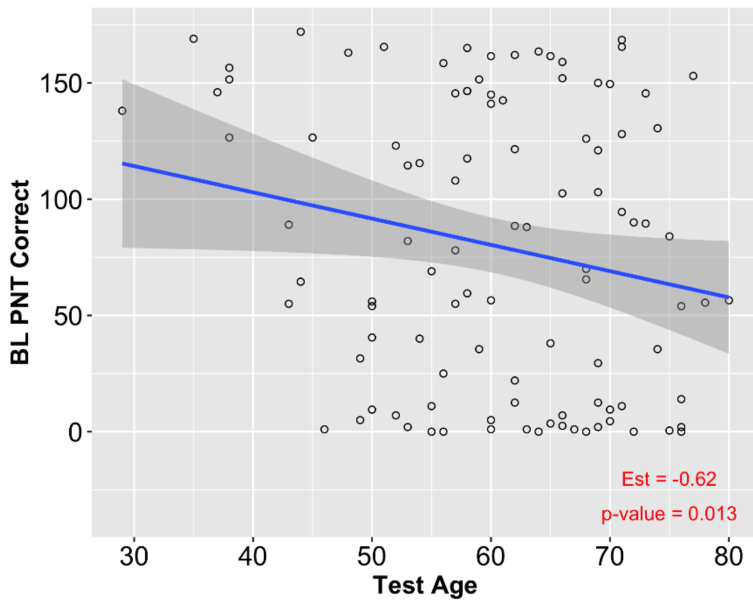

Figure 4.3 Test Age and PNT Baseline Scores

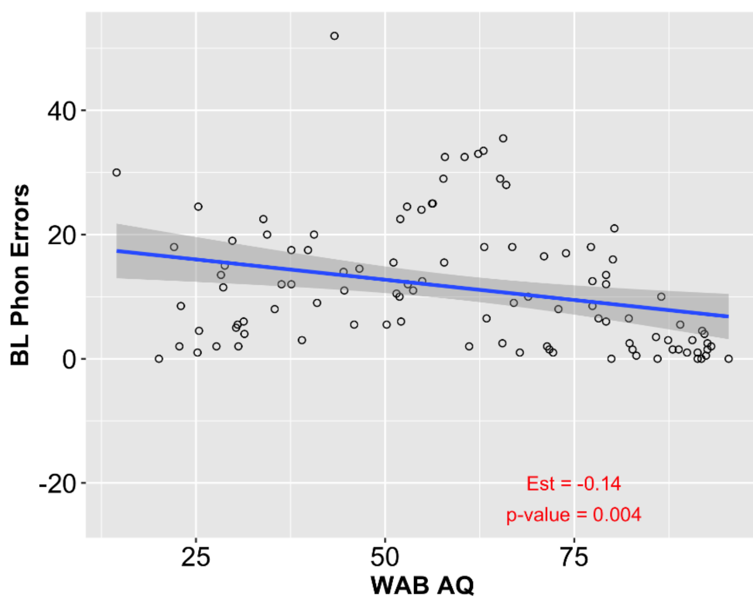

Figure 4.4 WAB AQ and PNT Baseline Phonemic Errors

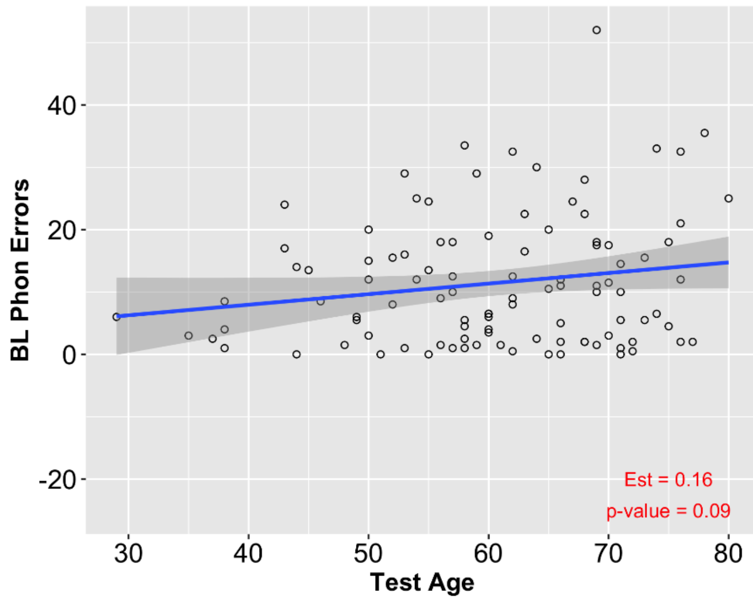

Figure 4.5 Test Age and PNT Baseline Phonemic Errors

Table 4.2 Linear Regression Model Results (Models 1-3)

			Multiple Linear Regression Model Results				
			Est.	*Std. Error*	*t Stat*	*p Value*	*Adj. R^2 (p-value)*
N=102	Model 1 (BL PNT)	*(Intercept)*	-21.73	18.47	-1.18	0.2421	0.8177 (< 2.2e-16)
		WAIS Total	2.44	0.12	19.88	<2e-16	
		WAB AQ	-0.62	0.25	-2.51	0.014	
		Test Age	-0.58	0.50	-1.16	0.2499	
	Model 2 (BL Phon)	*(Intercept)*	8.08	7.04	1.15	0.25403	-0.01758 (0.7402)
		WAIS Total	-0.003	0.02	-0.13	0.894	
		WAB AQ	-0.004	0.05	-0.10	0.924	
		Test Age	0.09	0.09	1.02	0.312	
	Model 3 (BL Sem)	*(Intercept)*	4.17	3.37	1.24	0.219	0.08199 (0.00977)
		WAIS Total	-0.14	0.05	-2.91	0.00445	
		WAB AQ	0.16	0.09	1.69	0.09462	
		Test Age	0.16	0.19	0.81	0.41834	

Model 4 had one significant main effect, WAB AQ, which indicated that baseline PNT scores were associated with more mild aphasia (β=2.27; p<0.00001; Fig. 4.6). Similarly, Model 5, with baseline phonological errors as the dependent variable, had one statistically significant main effect of WAB AQ (β=-0.14; p=0.01), which demonstrates that individuals with more mild aphasia produced less phonemic errors (Fig. 4.7). From

Model 6, the effects of VPM ratio correct trended toward statistical significance (β=-7.56; p=0.053) to predict baseline semantic errors (Fig. 4.8). Table 4.3 lists a full summary of the linear regression model results for Models 4-6.

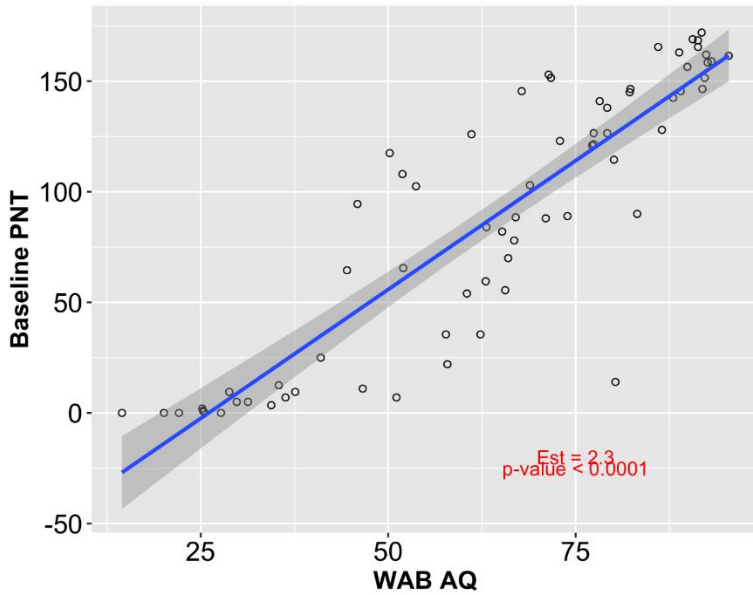

Figure 4.6 WAB AQ and Baseline PNT (N=69)

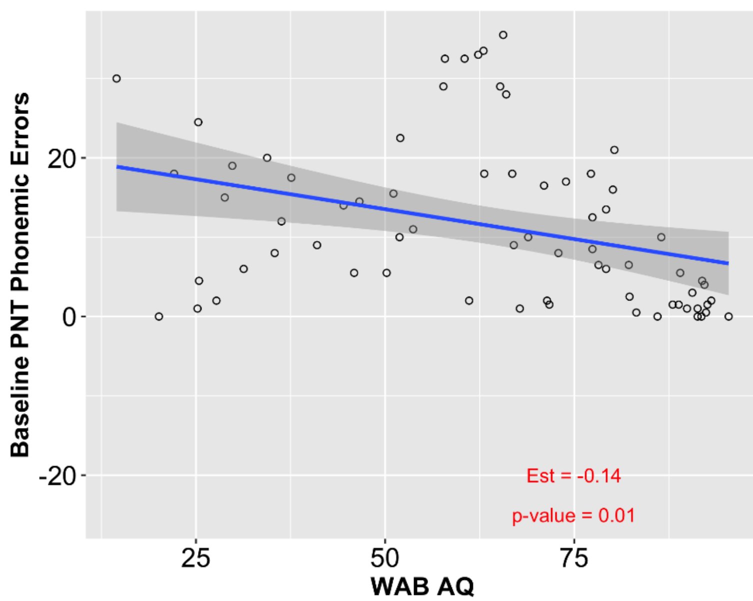

Figure 4.7 WAB AQ and Baseline PNT Phonemic Errors (N=69)

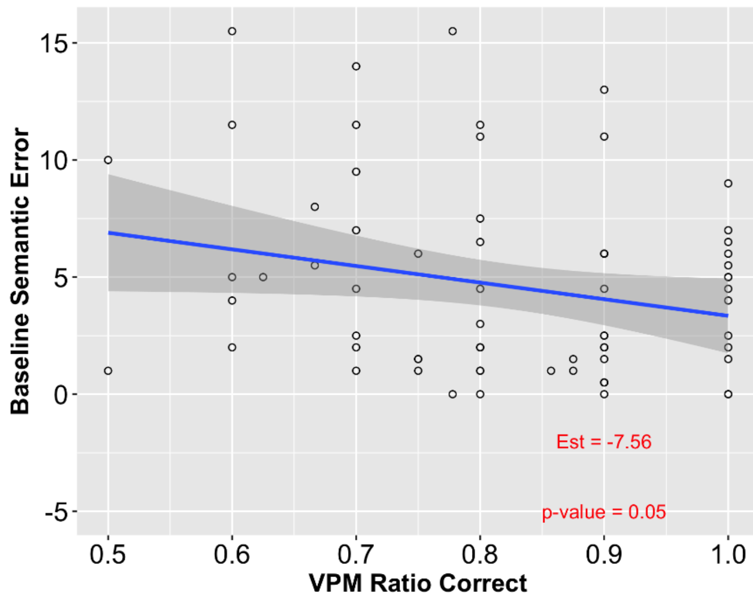

Figure 4.8 VPM Ratio Correct and Baseline Semantic Errors (N=69)

Table 4.3 Linear Regression Model Results (Models 4-6)

			Multiple Linear Regression Model Results				
			Est.	*Std. Error*	*t Stat*	*p Value*	*Adj. R^2 (p-value)*
N=69	Model 4 (BL PNT)	*(Intercept)*	-20.58	32.93	-0.63	0.5343	0.7794 (< 2.2e-16)
		VPM Ratio Correct	-8.70	26.70	-0.33	0.7457	
		RR Ratio Correct	10.25	24.62	0.42	0.6785	
		WAB AQ	2.27	0.16	13.81	<2e-16	
		Test Age	-0.57	0.32	-1.78	0.0791	
	Model 5 (BL Phon)	*(Intercept)*	13.90	11.18	1.24	0.2180	0.1193 (0.01596)
		VPM Ratio Correct	-9.24	9.06	-1.02	0.3118	
		RR Ratio Correct	5.74	8.35	0.69	0.4946	
		WAB AQ	-0.14	0.06	-2.59	0.0118	
		Test Age	0.19	0.11	1.74	0.0870	
	Model 6 (BL Sem)	*(Intercept)*	9.32	4.74	1.97	0.0533	0.0004489 (0.4102)
		VPM Ratio Correct	-7.56	3.84	-1.97	0.0533	
		RR Ratio Correct	1.34	3.54	0.38	0.7062	
		WAB AQ	0.005	0.02	0.21	0.8366	
		Test Age	0.01	0.05	0.18	0.8616	

Aim 2 – Post-Treatment Models

Six post-treatment models were created to investigate what factors predict 1) Overall PNT change scores, 2) Phonological error change scores, and 3) Semantic error

change scores. As in the Aim 1 models, the first set of models used data from the full set of participants (N=102), and the second set of models used data from a subset of those participants (N=69). Independent variables included in Models 7 through 9 were WAIS Matrix Reasoning scores, WAB AQ, and age at testing. The independent variables for Models 10 through 12 were visual pattern-matching (VPM) ratio correct, relational reasoning (RR) ratio correct, WAB AQ, and age at testing.

Model 7 included WAIS Total, WAB AQ, and test age as independent variables to predict PNT change. No significant factors were revealed from Model 7. Model 8, which aimed to predict change in phonological errors revealed one statistically significant predictor (WAB AQ), illustrated in Fig. 4.9. Here, a higher WAB AQ at baseline resulted in a greater reduction in phonemic errors (β=-0.07; p=0.01), while lower WAB AQ resulted in a greater increase in phonemic errors. Finally, there were no statistically significant values revealed from Model 9, which aimed to predict change in semantic errors. Table 4.4 lists a full summary of the linear regression model results for Models 7-9.

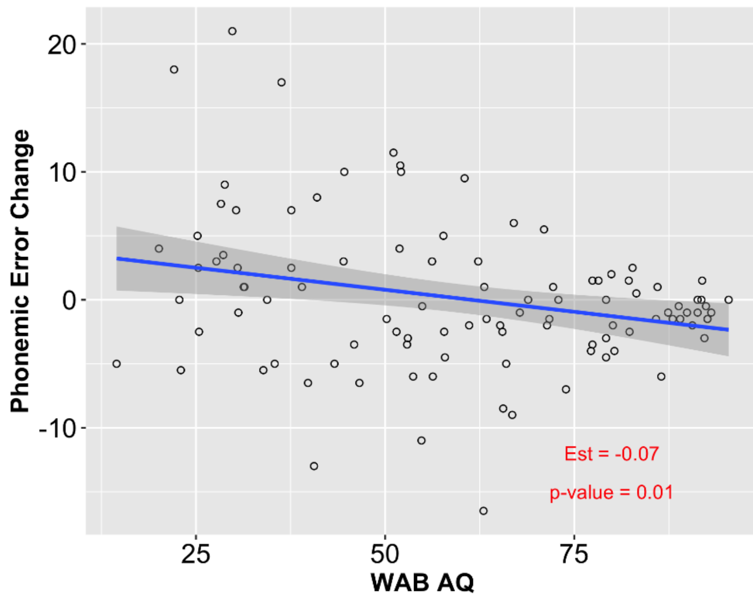

Figure 4.9 WAB AQ and Change in Phonemic Errors

Table 4.4 Linear Regression Model Results (Models 7-9)

			Multiple Linear Regression Model Results				
			Est.	*Std. Error*	*t Stat*	*p Value*	*Adj. R^2 (p-value)*
N=102	Model 7 (Δ PNT)	*(Intercept)*	12.73	7.81	1.63	0.106	0.005601 (0.3178)
		WAIS Total	-0.17	0.21	-0.81	0.418	
		WAB AQ	0.07	0.05	1.28	0.205	
		Test Age	-0.14	0.10	-1.38	0.172	
	Model 8 (Δ Phon)	*(Intercept)*	1.31	4.05	0.32	0.74714	0.04911 (0.04748)
		WAIS Total	0.05	0.11	0.42	0.67618	
		WAB AQ	-0.07	0.03	-2.64	0.00973	
		Test Age	0.04	0.05	0.76	0.45139	
	Model 9 (Δ Sem)	*(Intercept)*	0.74	2.50	0.30	0.769	-0.01352 (0.6487)
		WAIS Total	0.02	0.07	0.27	0.790	
		WAB AQ	-0.02	0.01	-1.27	0.208	
		Test Age	0.001	0.03	0.03	0.974	

The final set of models included the following independent variables: VPM ratio correct, RR ratio correct, WAB AQ scores, and test age. Model 10, which aimed to predict PNT change, had one significant effect of WAB AQ (β=0.14; p=0.03), illustrated in Fig. 4.10, indicating that individuals with less severe aphasia were more likely to improve on the PNT post-treatment. Also from Model 10, the effects of RR ratio correct

(β=-18.10; *p*=0.07) trended toward statistical significance, see Fig. 4.11, potentially indicating that those with a higher RR ratio correct score had less gain in their overall PNT score. VPM ratio scores and age at testing were not significant predictors of PNT change scores for this subset of participants. WAB AQ was again the only statistically significant effect revealed to predict change in phonological errors (Model 11; β=-0.12; *p*=0.0003), illustrated in Fig. 4.12. VPM ratio scores, RR ratio scores, and age at testing were not significant predictors of change in phonemic errors in this subset of participants. Finally, there were no significant factors revealed to predict change in semantic errors (Model 12). Table 4.5 lists a full summary of the linear regression model results for Models 10-12.

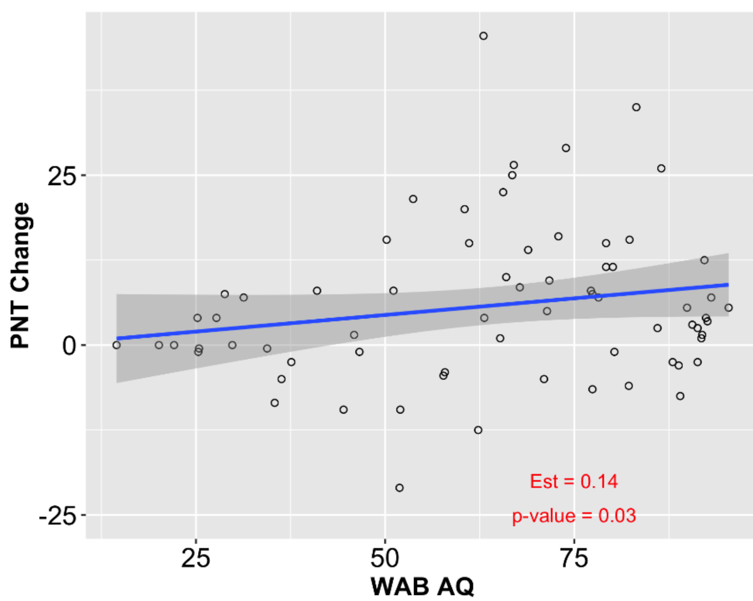

Figure 4.10 WAB AQ and Change in PNT (N=69)

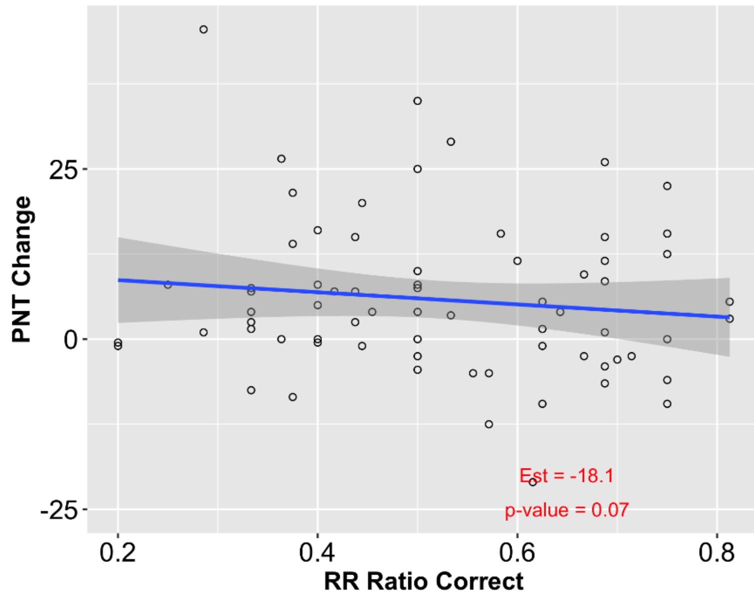

Figure 4.11 RR Ratio Correct and Change in PNT (N=69)

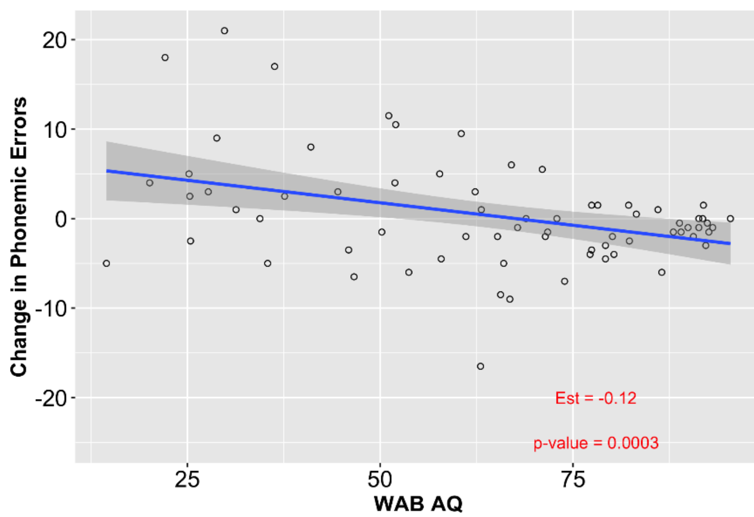

Figure 4.12 WAB AQ and Change in Phonemic Errors (N=69)

Table 4.5 Linear Regression Model Results (Models 10-12)

			Multiple Linear Regression Model Results				
			Est.	*Std. Error*	*t Stat*	*p Value*	*Adj. R^2 (p-value)*
N=69	Model 10 (Δ PNT)	*(Intercept)*	12.20	13.12	0.93	0.3559	0.03492 (0.1813)
		VPM Ratio Correct	-1.32	10.64	-0.12	0.9019	
		RR Ratio Correct	-18.10	9.81	-1.85	0.0696	
		WAB AQ	0.14	0.07	2.18	0.0329	
		Test Age	-0.08	0.13	-0.65	0.5174	
	Model 11 (Δ Phon)	*(Intercept)*	-1.05	6.54	-0.16	0.872567	0.1529 (0.005322)
		VPM Ratio Correct	8.05	5.30	1.52	0.134183	
		RR Ratio Correct	5.72	4.89	1.17	0.246961	
		WAB AQ	-0.12	0.03	-3.79	0.000333	
		Test Age	-0.004	0.06	-0.07	0.945580	
	Model 12 (Δ Sem)	*(Intercept)*	-2.37	4.14	-0.57	0.569	-0.02467 (0.6706)
		VPM Ratio Correct	2.67	3.36	0.80	0.429	
		RR Ratio Correct	1.00	3.09	0.33	0.747	
		WAB AQ	-0.03	0.02	-1.26	0.214	
		Test Age	0.01	0.04	0.46	0.646	

CHAPTER 5

DISCUSSION

The present study sought to identify the impact of nonlinguistic cognitive reserve on naming ability following language-based aphasia treatment. Six models were created to address Aim 1. The first three models investigated the association of WAIS scores, WAB AQ, and age at testing with overall naming performance as well as the prevalence of phonemic and semantic naming errors, all at baseline. The second set of three models investigated the association of visual pattern-matching (VPM) ratio correct, relational reasoning (RR) ratio correct, WAB AQ, and age at testing with baseline naming performance, phonemic errors, and semantic errors. VPM and RR scores were derived from the Wechsler Adult Intelligence Scale (WAIS) Matrix Reasoning subtest to differentiate between test items that require higher-level reasoning skills (RR test items) in keeping with Baldo et al. (2010). Models 4-6 utilized data from a subset (N=69) of the full set of participants (N=102) used for Models 1-3.

Six post-treatment models were created to address Aim 2, examining the association of factors of interest with post-treatment change in naming performance, change in phonemic errors, and change in semantic errors. The factors of interest for Models 7-9 were WAIS scores, WAB AQ, and age at testing. Finally, Models 10-12 investigated the following factors of interest: VPM ratio correct, RR ratio correct, WAB AQ, and age at testing.

For Aim 1, it was hypothesized that there would be no relationship between WAIS scores and baseline PNT scores or baseline phonemic errors. However, it was hypothesized that there would be a relationship between WAIS scores and greater baseline semantic errors. Consistent with this hypothesis WAIS scores do not predict baseline PNT scores outside of what is predicted by WAB AQ and age at testing. Also, in keeping with Aim 1 hypotheses, no relationship was found between WAIS scores and baseline phonemic errors. Instead, WAB AQ was a significant predictor of baseline phonemic errors and age at testing was a trending predictor. In contrast to the hypotheses, however, there was also no relationship between WAIS scores and baseline semantic errors. Overall WAIS scores did not predict baseline semantic errors. However, VPM ratio correct scores trended toward statistical significance for one baseline measure with a higher VPM ratio correct, resulting in fewer baseline semantic errors. RR ratio correct was not a significant predictor for any baseline measure.

To address Aim 2, it was hypothesized that there would be a relationship between WAIS scores and response to naming treatment overall and by error type. Higher WAIS scores, representing greater potential for learning, would predict greater response to naming treatment overall. It was also predicted that higher WAIS scores would result in a decrease in semantic errors and possibly an increase in phonemic errors. Additionally, RR ratio correct scores would be a better predictor of naming gains than VPM ratio correct. From Models 7 through 9, WAB AQ predicted change in phonemic errors with a lower WAB AQ resulting in more post-treatment naming errors, which is likely due to an increase in participant naming attempts compared to baseline, resulting in more errors. Finally, models 10 through 12 revealed that WAB AQ was a significant predictor of

overall PNT change scores as well as change in phonemic errors, and RR ratio correct scores were a trending predictor for overall PNT change scores. Participants with a higher RR ratio correct had less overall change in PNT score. While this result differs from the predicted result, this relationship could indicate that the participants with a greater facility for RR test items had higher baseline naming scores and, therefore, less room for naming gains.

Aphasia is heterogeneous in nature, and no two people diagnosed with aphasia will experience deficits in the same way (Fridriksson et al., 2018). While research has shown that behavioral aphasia treatment is effective (Brady et al., 2016; Breitenstein et al., 2017), not all individuals respond to treatment in the same way and predicting aphasia treatment outcomes is still challenging (Fridriksson & Hillis, 2021). Some factors that have been shown to impact aphasia treatment outcomes include age and aphasia severity (Gilmore et al., 2019; Holland et al., 2017; Kristinsson et al., 2021). Consistent with Kristinsson et al. (2021), aphasia severity was the most consistent predictor of response to naming treatment in that the more mild in aphasia severity, the more treatment gains made. As the present study utilized data from the same participants, these effects were expected. Their study concluded that participants with milder aphasia respond better to semantic treatment, whereas participants with more severe aphasia benefit more from phonological treatment (Kristinsson et al., 2021).

While effective language processing necessitates both linguistic and nonlinguistic cognitive abilities, cognition’s impact on aphasia treatment is still debated, despite the cooccurrence of nonlinguistic cognitive deficits with aphasia. Studies have shown that aphasia is associated with attention, executive function, and short-term memory

impairments (Villard & Kiran, 2015; Purdy, 2002; Lang & Quitz, 2012;). Even with this knowledge, traditional aphasia treatment targets linguistic deficits but does not necessarily take concomitant cognitive deficits into account. Furthermore, cognitive deficits might be difficult to diagnose in PWAs as many cognitive assessments require language use (Helm-Estabrooks, 2002). Research has shown that baseline linguistic and nonlinguistic cognitive abilities impact naming gains following treatment (Dignam et al., 2017) and that pretreatment nonlinguistic cognitive skills have a greater impact on naming treatment than sentence comprehension treatment (Gilmore et al., 2019). Previous studies also support the role of language in higher-level reasoning and problem solving (Baldo et al., 2010). The present study provides some mild additional evidence that baseline cognitive reserve, specifically relational reasoning ability, impacts response to naming treatment. However, there is no evidence to support that cognitive reserve impacts treatment effects specific to phonological or semantic error types. Furthermore, the results of the present study suggest that cognitive ability is separate from naming performance.

This study adds to our collective understanding of how cognitive reserve impacts successful aphasia rehabilitation. In theory, recognizing a patient’s baseline cognitive ability could aid clinicians in determining eligibility for aphasia treatment and in predicting treatment response. This is an important clinical consideration, as patient insurance limitations often necessitate treatment be as efficient as possible to maximize gains from a limited therapy duration. However, the current study did not find strong evidence that such extralinguistic cognitive ability is a firm predictor of baseline naming ability or treatment response. Of course, it will be important to determine the benefit of

concurrent cognitive-linguistic treatment. Should such a benefit be found, future research into cognition and aphasia could support the development of aphasia rehabilitation approaches that integrate cognitive and linguistic treatments.

Limitations

Several limitations of this study should be noted. First, this study was retrospective; therefore, measures of nonlinguistic cognition were limited. No single task is a perfect measure of cognition, let alone a measure of cognition in PWAs (Helm-Estabrooks, 2002). Cognition and language are often overlapping in nature, which is why there is much debate on appropriate nonlinguistic cognitive tasks, particularly for those with aphasia (Helm-Estabrooks, 2002). While the WAIS Matrix Reasoning subtest measures nonlinguistic cognition, it provides an incomplete assessment. This subtest measures visual information processing and abstract reasoning but does not explicitly measure attention, short-term memory, or executive function, all of which have been previously associated with aphasia and could potentially impact aphasia treatment response. An ideal measure would also assess these aspects of nonlinguistic cognition. Another challenge in the present study was the WAIS Matrix Reasoning discontinuation rule, which adherence to resulted in an incomplete dataset. There is no guarantee that a participant who discontinues the assessment early would, in fact, have missed later test items. The discontinuation rule also made assigning VPM and RR scores problematic, and proportion scores were not a perfect measure. The discontinuation rule often results in participants not being exposed to any RR test items. If participants do discontinue early and are not exposed at all to RR test items, then their proportion of RR items would be nonexistent, resulting in missing data points. In this study, such participants were

removed from statistical analysis. While a more limited sample was used to address limitations resulting from the discontinuation rule, the cut-off point of five RR test items was selected somewhat arbitrarily. This cut-off point ensured a minimum number of RR items for the ratio correct calculations while maintaining a relatively large sample size. However, using an arbitrary cut-off point is not ideal. Finally, it is worth noting that, in some cases, VPM and RR cannot completely be teased apart. Some test items contain aspects of both VPM and RR, making them difficult to categorize. It is possible that, for such items, some participants might use a VPM strategy to form a solution, while other participants might use a RR strategy. See Figures 3.1 and 3.2 for examples of such test items. For this study, items that had elements of both VPM and RR were considered relational reasoning test items as this is the more complex process.

Conclusions

The present study examined the relationship between cognitive reserve, baseline naming ability, and response to naming treatment. Results from this study provide limited evidence of a relationship between baseline cognitive reserve and response to naming treatment, and there is no evidence to suggest that cognitive reserve impacts treatment response in terms of specific error types. Future research would benefit from further examining the impact of additional measures of nonlinguistic cognition, including attention, executive function, and memory on naming treatment. Another direction would be to examine the relationship between nonlinguistic cognition and aphasia type-specific profiles of linguistic and cognitive deficits that could impact aphasia treatment outcomes. Future studies could also examine behavioral and neuroimaging data to gain a clearer understanding of the interaction between linguistic and nonlinguistic cognition.

REFERENCES

Baldo, J. V., Dronkers, N. F., Wilkins, D., Ludy, C., Raskin, P., & Kim, J. (2005). Is problem solving dependent on language?. *Brain and language, 92*(3), 240-250.

Baldo, J. V., Bunge, S. A., Wilson, S. M., & Dronkers, N. F. (2010). Is relational reasoning dependent on language? A voxel-based lesion symptom mapping study. *Brain and language, 113*(2), 59-64.

Baldo, J. V., Paulraj, S. R., Curran, B. C., & Dronkers, N. F. (2015). Impaired reasoning and problem-solving in individuals with language impairment due to aphasia or language delay. *Frontiers in Psychology*, *6*, 1523.

Basilakos, A., Stark, B. C., Johnson, L., Rorden, C., Yourganov, G., Bonilha, L., & Fridriksson, J. (2019). Leukoaraiosis is associated with a decline in language abilities in chronic aphasia. *Neurorehabilitation and neural repair, 33*(9), 718-729.

Basso, A., De Renzi, E., Faglioni, P., Scotti, G., & Spinnler, H. (1973). Neuropsychological evidence for the existence of cerebral areas critical to the performance of intelligence tasks. *Brain, 96*(4), 715-728.

Brady, M. C., Kelly, H., Godwin, J., Enderby, P., & Campbell, P. (2016). Speech and language therapy for aphasia following stroke. *Cochrane database of systematic reviews*, (6).

Breitenstein, C., Grewe, T., Flöel, A., Ziegler, W., Springer, L., Martus, P., ... & Bamborschke, S. (2017). Intensive speech and language therapy in patients with chronic aphasia after stroke: a randomised, open-label, blinded-endpoint, controlled trial in a health-care setting. *The Lancet, 389*(10078), 1528-1538.

Christoff, K., Prabhakaran, V., Dorfman, J., Zhao, Z., Kroger, J. K., Holyoak, K. J., & Gabrieli, J. D. (2001). Rostrolateral prefrontal cortex involvement in relational integration during reasoning. *Neuroimage*, *14*(5), 1136-1149.

Darley, F. L. (1972). The efficacy of language rehabilitation in aphasia. *Journal of Speech and Hearing Disorders, 37*(1), 3-21.

DeShon, R. P., Chan, D., & Weissbein, D. A. (1995). Verbal overshadowing effects on Raven's Advanced Progressive Matrices: Evidence for multidimensional performance determinants. *Intelligence*, *21*(2), 135-155.

Dignam, J., Copland, D., O'Brien, K., Burfein, P., Khan, A., & Rodriguez, A. D. (2017). Influence of cognitive ability on therapy outcomes for anomia in adults with chronic poststroke aphasia. *Journal of Speech, Language, and Hearing Research, 60*(2), 406-421.

El Hachioui, H., Visch-Brink, E. G., Lingsma, H. F., van de Sandt-Koenderman, M. W., Dippel, D. W., Koudstaal, P. J., & Middelkoop, H. A. (2014). Nonlinguistic cognitive impairment in poststroke aphasia: a prospective study. *Neurorehabilitation and Neural Repair, 28*(3), 273-281.

Fridriksson, J., Yourganov, G., Bonilha, L., Basilakos, A., Den Ouden, D. B., & Rorden, C. (2016). Revealing the dual streams of speech processing. *Proceedings of the National Academy of Sciences, 113*(52), 15108-15113.

Fridriksson, J., den Ouden, D. B., Hillis, A. E., Hickok, G., Rorden, C., Basilakos, A., ... & Bonilha, L. (2018). Anatomy of aphasia revisited. *Brain, 141*(3), 848-862. Fridriksson, J., & Hillis, A. E. (2021). Current approaches to the treatment of post-stroke aphasia. *Journal of Stroke, 23*(2), 183.

Gilmore, N., Meier, E. L., Johnson, J. P., & Kiran, S. (2019). Nonlinguistic cognitive factors predict treatment-induced recovery in chronic poststroke aphasia. *Archives of physical medicine and rehabilitation, 100*(7), 1251-1258.

Goodglass, H., & Kaplan, E. (1972). *The Boston Diagnostic Aphasia Examination.* Philadelphia: Lea & Febiger.

Heaton, R., Chelune, G. J., Talley, J. L., Kay, G. G., & Curtis, G. (1993). *Wisconsin card sorting test (WCST) manual revised and expanded*. Odessa, FL: Psychological Assessment Resources.

Helm-Estabrooks, N. (2001). *Cognitive Linguistic Quick Test*. San Antonio, TX: The Psychological Corporation.

Helm-Estabrooks, N. (2002). Cognition and aphasia: a discussion and a study. *Journal of communication disorders, 35*(2), 171-186.

Hilari, K. (2011). The impact of stroke: are people with aphasia different to those without?. *Disability and rehabilitation, 33*(3), 211-218.

Holland, A., Fromm, D., Forbes, M., & MacWhinney, B. (2017). Long-term recovery in stroke accompanied by aphasia: A reconsideration. *Aphasiology, 31*(2), 152-165.

Johnson, L., Nemati, S., Bonilha, L., Rorden, C., Basilakos, A., Newman-Norlund, R., Hillis, A. E., Hickok, G., Fridriksson, J. (2022). Predictors Beyond the Lesion: Health and Demographic Factors Associated with Aphasia Severity. *Cortex.*

Joseph, R. (1988). The right cerebral hemisphere: Emotion, music, visual-spatial skills,

body-image, dreams, and awareness. *Journal of clinical psychology, 44*(5), 630-673.

Kertesz, A. (2007). *Western Aphasia Battery-Revised*. San Antonio, TX: Pearson.

Kristinsson, S., Basilakos, A., Elm, J., Spell, L. A., Bonilha, L., Rorden, C., ... & Fridriksson, J. (2021). Individualized response to semantic versus phonological aphasia therapies in stroke. *Brain Communications, 3*(3), fcab174.

Lang, C. J., & Quitz, A. (2012). Verbal and nonverbal memory impairment in aphasia. *Journal of Neurology, 259*(8), 1655-1661.

McNeil, M. R., Odell, K., & Tseng, C. H. (1991). Toward the integration of resource allocation into a general theory of aphasia. *Clinical aphasiology, 20*, 21-39.

Mueller, J. A., & Dollaghan, C. (2013). A systematic review of assessments for identifying executive function impairment in adults with acquired brain injury. *Journal of Speech, Language, and Hearing Research, 56*(3), 1051-1064.

Papathanasiou, I., & Coppens, P. (2017). *Aphasia and related neurogenic communication disorders.* Jones & Bartlett Learning.

Peach, R. K. (2017, February). Cognitive approaches to aphasia treatment: application of the cognition of language to aphasia intervention. In *Seminars in Speech and Language* (Vol. 38, No. 01, pp. 003-004). Thieme Medical Publishers.

Purdy, M. (2002). Executive function ability in persons with aphasia. *Aphasiology, 16*(4-6), 549-557.

Raven, J. C. (1965). *Guide to using the Coloured Progressive Matrices*. London: H. K. Lewis.

Raven, J. C., Court, J. H., & Raven, J. (1979). *Manual for Raven's progressive matrices and vocabulary scales*. London: Lewis & Co.

Roach, A., Schwartz, M. F., Martin, N., Grewal, R. S., & Brecher, A. (1996). The Philadelphia naming test: scoring and rationale. *Clinical aphasiology, 24*, 121-133.

Rosenich, E., Hordacre, B., Paquet, C., Koblar, S. A., & Hillier, S. L. (2020). Cognitive reserve as an emerging concept in stroke recovery. *Neurorehabilitation and neural repair, 34*(3), 187-199.

Ross, K., & Wertz, R. (2003). Quality of life with and without aphasia. *Aphasiology, 17*(4), 355-364.

Salthouse, T. A. (2009). When does age-related cognitive decline begin?. *Neurobiology of aging, 30*(4), 507-514.

Sinotte, M. P., & Coelho, C. A. (2007). Attention training for reading impairment in mild aphasia: A follow-up study. *NeuroRehabilitation, 22*(4), 303-310.

Spell, L. A., Richardson, J. D., Basilakos, A., Stark, B. C., Teklehaimanot, A., Hillis, A. E., & Fridriksson, J. (2020). Developing, implementing, and improving assessment and treatment fidelity in clinical aphasia research. *American Journal of Speech-Language Pathology, 29*(1), 286-298.

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the international neuropsychological society*, *8*(3), 448-460.

Villard, S., & Kiran, S. (2015). Between-session intra-individual variability in sustained, selective, and integrational nonlinguistic attention in aphasia. *Neuropsychologia*, *66*, 204-212.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale-Revised*. San Antonio, TX: The Psychological Corporation.

Wechsler, D. (2008). *Wechsler adult intelligence scale–Fourth Edition (WAIS–IV)*. San Antonio, TX: NCS Pearson.

Wilmskoetter, J., Marebwa, B., Basilakos, A., Fridriksson, J., Rorden, C., Stark, B. C., ... & Bonilha, L. (2019). Long-range fibre damage in small vessel brain disease affects aphasia severity. *Brain, 142*(10), 3190-3201.