ABSTRACT

Title of Thesis: THE ROLE OF PROCESSING SPEED AND COGNITIVE CONTROL DURING WORD RETRIEVAL IN PERSONS WITH APHASIA

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It is possible that word retrieval is not associated with general processing speed but is associated with a highly specific cognitive process - that of inhibiting competing alternative words. This study aims to measure domain general processing speed, domain general cognitive control, domain specific linguistic processing, and domain specific linguistic selection control. Twelve PWA and 15 neurotypical controls completed all four tasks. *Results:* domain general processing speed and domain general cognitive control response times differed between the groups but were nonsignificant. In neurotypical adults, word retrieval response time was predicted by domain general measures. However, this pattern was not observed in PWA – rather, word retrieval was predicted by domain specific linguistic measures. The implications of these findings indicate that aphasia is ultimately defined by language deficits, and increased word retrieval times in PWA cannot be attributed to a generalized processing speed deficit.

THE ROLE OF PROCESSING SPEED AND COGNITIVE CONTROL DURING WORD RETRIEVAL IN PERSONS WITH APHASIA

by

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List of Abbreviations

PWA – Persons with Aphasia

RT – Response Time

WAB-R – Western Aphasia Battery, Revised

AQ – Aphasia Quotient

TOT – Tip of the Tongue

RAN – Rapid Automatized Naming

Chapter 1: Introduction

Background Information

Aphasia is an acquired selective impairment of language modalities resulting from focal lesions in the language dominant hemisphere (Papathanasiou & Coppens, 2017). The most prominent and prevalent symptom of aphasia is a word retrieval difficulty (Schwartz et al., 2009). While there are many competing ideas as to what, why, or how word retrieval deficits occur, one statement has consistently been identified as true. Persons with aphasia (PWA) report lower social engagement and quality of life due to communication impairments – primarily word retrieval deficits (Howard & Gatehouse, 2006). Word retrieval has been found to be not only inaccurate, but also significantly delayed in PWA. In fact, PWA can take twice the time as neurotypical adult speakers to retrieve a word (Galletta & Goral, 2018; Pompon, McNeil, Spencer, & Kendall, 2015). It is unknown if these increased word retrieval latencies are restricted to domain specific linguistic processing in PWA, or if there is a generalized slowing across multiple cognitive domains. Further, it is unclear if generalized slowing (if present) contributes to word retrieval latencies or if word retrieval deficits are independent of generalized slowing in PWA. Given that slowed processing has been associated with a wide range of cognitive functions in older adults (Salthouse, 1996), it can be hypothesized that general cognitive slowing across multiple cognitive domains will influence word retrieval in PWA.

For instance, generalized processing speed on the Cognitive Performance Test was found to correlate with functional independence in acute stroke patients

(Loranger, Lussier, Pepin, Hopps, & Senecal, 2000), indicating a connection between generalized processing speed and functional independence. Conversely, it is possible that word retrieval is not associated with domain general measures but is associated with a highly specific linguistic measures cognitive process - that of inhibiting competing alternative words. The potential inter-relationship between domain general measures and word retrieval response times in PWA has not been systematically investigated and is the focus of this study.

Clinicians and researchers are both continually interested in developing word retrieval interventions that have increased therapeutic results as this feature of aphasia is the largest factor decreasing PWA's quality of life and involvement in activities of daily living. Should the results of this study find domain general processing is related to domain specific linguistic processing and linguistic selection control, word retrieval treatments should be devised to co-treat domain general processing and domain specific linguistic processing. Surprisingly, a few researchers have already jumped to co-treatment and have created experimental designs treating word retrieval deficits alone and combining word retrieval and domain general processing speed (Conroy, Sotiropoulou, Humphreys, Halai, & Lambon, 2018; Manie, Mehri, Khatoonabadi, & Murray, 2018). However, a study that isolates and measures word retrieval and domain general processing speed in PWA has not been conducted.

The following sections provide relevant background on word retrieval, domain general processing, domain specific linguistic processing, and domain general cognitive control and what is currently known about their inter-relationships.

Word Retrieval

To articulate a word, the speaker needs to rapidly perform a series of mental processes, including lemma selection, word form retrieval, and articulatory planning (Dell, Chang, Griffin, 1999; Indefrey & Levelt, 2004). A meta-analysis of chronometric and neuroimaging findings indicates that these processes occur rapidly and in quick succession, as indicated in Table 1 (Indefrey, 2011; Indefrey & Levelt, 2004). Lexical selection initially involves activation of semantically related targets, which get activated because of the overlap in semantic features. For example, if a person thinks of "fish", this activates semantically similar targets such as "whale" and "shark." Similarly, at the word form level, relevant phonemes need to be selected from among phonologically similar neighbors (e.g., fill, fin, wish, etc. for "fish"). The selection of target word lemmas and corresponding word forms requires resolution of competition between different semantic and phonological competitors. This kind of cognitive control in the context of word production has been called selection control (Nozari et al., 2016). Given that multiple semantic and phonological candidates are activated and finally a single word must be selected, there is likely some amount of domain general cognitive control that is involved in lexical selection and ultimately word production (Dell et al., 1999; Faroqi-Shah, Sampson, Pranger, & Baughman, 2016; Levelt, 2001; Shao, Roelofs, & Meyer, 2012). PWA often produce paraphasias (i.e. saying "table" instead of "chair") and phonemic paraphasias (stating "breghtning" [a nonword] instead of "lightning") suggesting failures in domain specific linguistic selection control. Further, the rapid speed at which component processes occur suggests a potential role of domain general processing speed on word retrieval success. This forms the basis for examining the relationship between word retrieval, cognitive control and processing speed in the current study.

Table 1

Stages of Word Retrieval. Adapted from " The spatial and temporal signatures of word production components: A critical update, by Indefrey (2011).

Word Retrieval Phase	**Duration (in milliseconds)**
Lemma Selection	0 – 175 ms
Lexical Word Form Encoding	175 – 250 ms
Phonological Code Retrieval	250 – 330 ms
Articulatory Planning	330 – 600 ms

Word retrieval is typically assessed through a variety of tasks (such as picture naming) and its performance is measured in terms of accuracy and reaction time (RT). Failures of word retrieval are often characterized by a feeling of "Tip of the tongue" (TOT), when a person knows the name of an item but cannot articulate the name. Word retrieval difficulties in PWA are considered to be similar to TOT in non-aphasic speakers. In one study, neurologically healthy participants were asked to indicate "known," "tip of the tongue," or "unknown" when presented with a picture and accuracy and RTs were measured (Shafto, Stamatakis, Tam, & Tyler, 2010). Interestingly, TOT responses had RTs in the range of 2,500-3,500 milliseconds, while known/unknown responses' RTs were 1,500-2,000 milliseconds. This indicates that neurologically healthy adults experiencing TOT took 1,000 milliseconds longer compared to trials with known/unknown stimuli. This provides a probable explanation that PWA may spend an additional 1,000 milliseconds during word retrieval compared to neurologically healthy adults. This raises the question, are domain general processes and domain specific linguistic processes activated during this TOT phenomena? Based on the background of word retrieval proposed by Indefrey and Levelt (2001), it is hypothesized that domain general processing and domain specific linguistic processing are involved in word retrieval.

What is known about word retrieval in PWA? PWA take twice as long compared to neurologically healthy peers (Galletta & Goral, 2018; Pompon et al., 2015 (extracted from Figure 1)). It is possible PWA have increased word retrieval RT because PWA need longer time for lemma and/or word form selection (Papathanasiou & Coppens, 2017). In PWA, lemma and word form level deficits could occur either due to impaired access of the representations or due to weakened representations themselves. Should there be impairment at the level of the lemma selection, the conceptualization of a target, a PWA may have semantic access deficit. Should an impairment occur at the level of the lexical word form representation, a PWA may have a phonological access or storage deficit. Regardless of the level at which the word retrieval process is impaired, PWA will have increased word retrieval RTs.

With increased word RTs in PWA, slowness can occur either from domain general slowing or from domain specific linguistic slowing. This introduces the need to measuring both domain general slowing and domain specific linguistic slowing by using simple tasks that minimize the cognitive demand placed on the participant. As domain specific linguistic slowing could occur at any point in the word retrieval process, many researchers use a simple lexical decision task to require participants to quickly identify whether a presented string of letters form a true English word, or a nonword. During the word retrieval process, as explained by Indefrey and Levelt

(2004), domain specific linguistic slowing could occur at the level of lexical selection or lexical word form encoding. Using a simple measure of lexical access infers the level of participants' domain specific linguistic processing. Thus, if any participants in this research study score less than 75% accuracy during any measure of domain specific linguistic task or domain general tasks, the respective data will be removed from that participant as it will be difficult to judge if slowing is due to weak lexical access or poor cognitive control. It has been suggested that when PWA have domain specific linguistic deficits and they also exhibit domain general cognitive control deficits (Van der Linden, Dricot, De Letter, Duyck, … & Szmalec, 2018). The lexical decision task, therefore, minimizes the opportunity for a participant to have mismatched lexical access and cognitive control performance by targeting domain specific linguistic control. Additional studies indicate that the frequency and complexity of lexical items included in the lexical decision task impact the performance of PWA (van Ewijk, & Avrutin, 2016). The lexical items included in the lexical decision task included in this experiment all maintain the same level of frequency and complexity, therefore accounting for the confounding factors found by can Ewijk & Avrutin (2016). For the purpose of this study, the lexical decision task was included as a measure of domain specific linguistic processing, or lexical access. Therefore, the lexical decision task is a measure of PWA's domain specific linguistic processing abilities during a nonverbal task.

One of the challenges of measuring word retrieval RTs in PWA is the highly variable involvement of motor planning deficits (apraxia) across PWA, which can confound typical word retrieval RT measures. In order to accurately measure components of word retrieval, the phoneme monitoring task will serve as a measure of selection and interference control within the linguistic domain (Shivabasappa & Krishnan, 2011). The phoneme monitoring task (Dijkstra, Roelofs, & Fieuws, 1995; Vroomen, & De Gelder, 1999) involves determining if a specific phoneme (e.g., /k/) is present in the name of a picture (e.g., a picture of a cat). The participant responds by pushing a button. Thus, this task engages all processes of word retrieval, including phonological code. However, oral production is not required, minimizing the confound of motor planning. Therefore, performance on the phoneme monitoring task is a measure of selection control rather than domain specific linguistic processing like the lexical decision task. The phoneme monitoring task has not been used as a measure of word retrieval in PWA, however it has been found in other studied populations to act as a true measure of word retrieval (Sasisekaran & De Nil, 2006; Shivabasappa & Krishnan, 2011; & Vroomen & De Gelder, 1999).

Processing Speed

Domain general processing speed, as measured by past researchers Salthouse (1994) and Kail & colleagues (1996) is described as a measure that is finite, indicating the longer a person takes to 'process' something, the greater likelihood a person has for losing the initial target. Domain general processing speed defined by Salthouse, therefore, can be viewed as an accurate representation of a person's cognitive ability, measured primarily by cognitive speed (Salthouse, 1994). Similar studies that use processing speed as a theoretical construct of cognitive speed are also found within the literature of rapid automatized naming (RAN) (Savage, McBreen, Genesee, Erdos, Haigh, & Nair, 2018). Researchers in childhood language development depend on RAN and domain general processing to measure cognitive abilities. The concept of domain general processing is included in this research as a measure of participants generalized processing necessary for successful word retrieval. Faroqi-Shah et al. (2016) suggests equally slowed domain general processing speed during incongruent and congruent trials in the PWA group, which suggesting a general deficit in domain general processing

As discussed in the previous section, increased word retrieval RTs in PWA can be caused by slowing in domain specific linguistic processing. A second suggestion is that the presence of slowed domain general processing causes increased word retrieval RTs in PWA. For the purposes of this research, two measures were used to evaluate processing speed, as defined by Salthouse (1994): domain general processing & domain specific linguistic processing. Processing speed, which refers to the ability to process information rapidly, is typically expressed as the RT to complete a certain simple cognitive, perceptual or psychomotor task. The RT is measured in paper and pencil (e.g. symbol search) or computer tasks (e.g. visual discrimination) (Carlozzi et al., 2015). Domain general processing speed can be measured using simple pattern comparison task that has minimized cognitive load. Domain specific processing refers to the ability to process information rapidly within a targeted domain (e.g. language, memory, emotion). In domain specific linguistic processing, which will be assessed using a lexical decision task (Evans, Hula, & Starns, 2018), the task requires participants to identify if the word is a true English word or nonword, inherently this task has minimal cognitive load and is a focused measure of domain specific linguistic processing. Published PWA data regarding the lexical decision task indicated a speed-accuracy trade off demonstrate a possible slowed domain-general processing as PWA require intentional effort to be both quick and accurate (Evans et al., 2018).

For instance, when one or more stages of word retrieval (Table 1) has slowed neural conduction, word retrieval RTs could increase in PWA. Given that slowed word naming in PWA could result from either slowed domain general processing or slowed processing within the language system (or both), it is important to tease these apart. A non-linguistic reaction time task, such as the pattern comparison task (Carlozzi et al., 2015), measures domain general processing speed while a lexical decision task is indicative of speed within the language system.

Thus far in the literature, a relationship between domain general processing and word retrieval in aphasia has not been explicitly studied. It is possible that by using the RTs of domain general processing (pattern comparison) and domain specific linguistic processing (lexical decision), a slowed general processing speed may be identified in PWA. Should word retrieval RTs mainly be affected by slowed domain general processing speed, RTs for both the lexical decision task and the pattern comparison task will correlated RTs.

Cognitive Control

Domain general cognitive control refers to the processes of detection and resolution of interference and the maintenance of goal-relevant representations (Faroqi-Shah et al., 2016). It is common to use the Stroop task to assess domain general cognitive control (Dash & Kar, 2014; Duell et al., 2018; Indefrey, 2011; Thompson et al., 2018; West & Alain, 2000). In its classic form (Stroop, 1936) the

Stroop task involves naming the font color of written words that refer to colors. The Stroop task incorporates cognitive control by adding mismatched font colors and written text (interference) during some trials and comparing performance between trials with (incongruent) and without interference (congruent) – the Stroop effect (Duell et al., 2017). Trials with interference require participants to use greater cognitive control (resolution of interference and goal maintenance) in order to perform the task. Typically, lower accuracy and increased RT on incongruent trials relative to congruent trials reflect poorer cognitive control (Dash & Kar, 2014; Faroqi-Shah, et al., 2016; Kuzmina & Weekes, 2017; Marinelli, et al., 2017; Neto & Santos, 2012; Pompon, et al., 2015; Purdy, 2002; Thompson, et al., 2018).

Domain general cognitive control has been found to change with age (Geva et al., 2012; Jacobson, Geist, & Mahone, 2018; Salthouse 1994; West & Alain, 2000), in PWA (Dash & Kar, 2014; Faroqi-Shah, et al., 2016; Kuzmina & Weekes, 2017; Marinelli, et al., 2017; Neto & Santos, 2012; Pompon, et al., 2015 ; Purdy, 2002; Thompson, et al., 2018), and in stroke (de Haan et al., 2006; Rasquin, Verhey, Lousberg, Winkens, & Lodder 2002; Su, Wuang, Lin, & Su, 2015). Stroop RTs from representative studies are given Table 2 to allow for direct comparison across groups. Table 2 shows that, for all trial types, PWA are slower than neurotypical speakers and within neurotypicals, older adults are slower than younger adults.

Table 2

Average Response Speed during the Stroop task. Adapted from Faroqi-Shah et al. (2016), Pompon et al. (2015), & West & Alain, (2000) represented in milliseconds.

	Neurotypical Controls				**PWA**	
	Young Adults (N=12)	**Older Adults (N=12)**	**(N=38)**	**(N=20)**	**(N=38)**	**(N=19)**
	West & Alain		*Faroqi-Shah et al.*	*Pompon et al.*	*Faroqi-Shah et al.*	*Pompon et al.*
Congruent	600	950	950	750	1,230	1,220
Incongruent	900	1500	1,090	900	1,400	1,750
Neutral	n/a	n/a	1,010	n/a	1,280	n/a
Stroop effect (incongruent minus congruent)	300	550	80	150	170	520

Regarding PWA performance during the Stroop task, Pompon et al. (2015) and Faroqi-Shah et al. (2016) found PWA had consistent (though nonsignificant) difficulty inhibiting throughout the task, suggesting cognitive control deficit. PWA had slower RT incongruent trials (Table 2), which is likely the contribution of domain general cognitive control. In terms of whether cognitive control is compromised, it is currently unclear. The Stroop effect in PWA is close to the neurotypical group in one study (Faroqi-Shah et al., 2016) and much exaggerated in another study (Pompon et al., 2015). In the present study, should probable domain general cognitive control deficits be identified, PWA will have a much slower RT during incongruent trials compared to congruent trials, results like the Pompon et al (2015) findings. Overall, these published studies support that PWA have increased RT during the Stroop task compared to neurologically healthy peers.

This ‘resolution of interference’ and ‘goal maintenance’ that are key components of domain general cognitive control in the Stroop task are also crucial for word retrieval selection control (Dell et al., 1999; Faroqi-Shah et al., 2016; Levelt, 2001; Nozari & Novick. 2017; Shao et al., 2012). This is evidenced in PWA through frequent productions of semantic paraphasias. The question is, whether general cognitive control deficits observed in PWA (as measured by the Stroop effect) and the impaired selection control for word retrieval arise from the same or different domain mechanism. While a few studies have examined the association between domain general cognitive control measures and word retrieval in neurologically healthy adults (Crowther & Martin, 2014; Shao et al., 2012), a few published studies have examined a probable relationship between cognitive control and word retrieval in PWA (Faroqi-Shah, et al., 2016; Pompon, et al., 2015). Faroqi-Shah, et al. (2016) examined the association between object naming accuracy and Stroop effect in monolingual and bilingual PWA and neurologically healthy adults. The authors did not find a significant correlation between these two measures in any participant group, although PWA showed deficient domain general cognitive control. Studies that have found an association between domain general cognitive control in word retrieval in neurologically healthy adults used more fine-grained measures such as picture naming speed (Shao et al, 2012) instead of accuracy, and semantic interference in blocked naming (Crowther & Martin, 2014). Thus, the lack of an association in PWA could have been the lack of granularity in object naming accuracy scores (compared to RT measures). Further, oral production measures in PWA (as measured by Faroqi-Shah et al., 2016) are impacted not only by weak language representations, but also by individual variation in motor planning issues and nonfluency. Therefore, it is important to re-test the association between word retrieval and domain general cognitive control in PWA by making two changes from the prior research: 1) use a RT measure for word retrieval, 2) use an experimental paradigm which measures domain specific linguistic selection control but does not rely on motor planning or a verbal response. In the present study, a phoneme monitoring task is used to measure linguistic selection control (Sasisekaran et al., 2006; Shivabasappa & Krishnan, 2011). This requires participants to access and mentally manipulate a presented phoneme, identify a presented picture, target the word form, and target the phonological code. The phoneme monitoring task integrates all components of lexical selection and measures participants' access to a multi-level linguistic knowledge of lexical items, which requires the use of domain general cognitive control.

To summarize, domain general cognitive slowing and general cognitive control could potentially contribute to word retrieval difficulties in PWA. Currently, the literature on domain general processing speed and cognitive control in PWA is an understudied area. Minimal studies have directly examined a direct association between cognitive control and word retrieval in PWA. As cognitive control and word retrieval are inarguably linked throughout recent research (Nozari & Novick, 2017) and suspected to be impaired in PWA (Faroqi-Shah, et al., 2016; Pompon, et al., 2015), however there have not been any studies that look to assess the level of domain general cognitive control in PWA and how it therefore relates to the hallmark symptom of aphasia, word retrieval deficits. Based on the reviewed literature, there are several hypotheses discussed below that aim to further the research on word retrieval deficits.

Chapter 2: Research Questions & Hypotheses

Research Questions & Hypotheses

Research Question 1

Is there a general cognitive slowing in aphasia, as measured by a processing speed task called Pattern Comparison? It is hypothesized that, relative to age and education – matched neurotypical adults, PWA will show slower processing speed (de Haan et al., 2006; Neto & Santos, 2012; Rasquin et al., 2002; Su et al., 2015).

Research Question 2

Is there a cognitive control deficit in PWA, as measured by the Stroop task? It is hypothesized that, relative to age and education – matched neurotypical adults, PWA will show decreased cognitive control, as measured by the Stroop effect (difference in response speed between incongruent and congruent trials on the Stroop task) (Caplan et al., 2011; Faroqi-Shah et al., 2016**;** Hoffman, Jefferies, Haffey, Littlejohns, & Lambon Ralph, 2013; Pompon et al., 2013; Sung et al., 2011).

Research Question 3

Do domain general processing speed RTs and domain general cognitive control task RTs predict word retrieval RTs, as measured by the phoneme monitoring task? Or, can word retrieval performance, as measured by the phoneme monitoring task, only be predicted by language performance as measured by; aphasia severity (WAB-AQ) and the lexical decision task? It is hypothesized that neurotypical adults' word retrieval will be influenced by cognitive control (Shao et al., 2012) but not by processing speed. In PWA, it is hypothesized that word retrieval will be influenced by both cognitive control and aphasia severity (Faroqi-Shah et al., 2016) and processing speed (Pompon et al., 2015).

Chapter 3: Methods

Study Design

The study recruited two groups of participants (PWA and neurotypical adults). In total, twelve PWA and fifteen neurotypical adults completed this experiment. Four computer-based tasks were used to address each of the following: domain general processing speed, domain general cognitive control, domain specific linguistic processing, and domain specific linguistic selection control. Participants' performance was compared between groups to address each research question (RQ). PWA's response speed in two tasks (pattern comparison and Stroop) were compared to neurotypical controls' performance to determine the extent and nature of cognitive slowing (RQ1) and control deficit (RQ2). A linear regression analysis was used to examine the impact of domain general processing speed, domain general cognitive control, language speed (lexical decision task) and aphasia severity on word retrieval (phoneme monitoring task) for RQ3.

Participants

Participants were recruited through the Aphasia Research Center and from the local community. Twelve PWA and fifteen age- and education-matched neurologically healthy controls were recruited. For PWA to be included in this study, the following inclusion criteria had to be met: > 6 months post aphasia onset, ability to comprehend simple comments [determined by a composite comprehension score of 4.4 by the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2007)], native English speakers, have a minimum high school education, and have passed the following screenings: vision (including visual field cuts), colorblindness, color-to-text association, WAB-R reading screening, section D (M=1, SD=0), hearing, and cognition. Through the color-to-text assessment and the WAB-R reading subtest all PWA demonstrated that they were able to read at the word level and did not exhibit lexical access deficits for color terms. Table 3 lists the response times for PWA when they completed the color-to-text association task.

Table 3

Response Times for the color-to-text screener. Responses represented in milliseconds

Participant	Condition		
	Correct Items (n=9)	*Incorrect Items (n=9)*	*Grand Total*
AP115	1,770	2,507	2,138
AP117	1,579	1,560	1,569
AP119	1,931	3,012	2,472
AP120	1,642	1,752	1,697
AP122	3,711	2,338	3,025
AP127	2,283	1,146	1,714
AP128	1,174	2,356	1,765
AP129	1,411	1,552	1,481
AP132	1,665	1,259	1,462
AP88	1,768	1,505	1,636
AP92	1,844	1,877	1,860
AP93	1,615	3,543	2,579

Table The WAB-R, Aphasia Quotient (AQ) was also calculated to be used as a predictive factor in research question three (the relationship between word retrieval, and domain general measures). Neurotypical controls were required to have a minimum high school education, be native speakers of English, pass the same screeners as the PWA, and additionally complete the Montreal Cognitive Assessment (MoCA; Nasreddine, et al., 2005). Each participant received a MoCA score of 26 or greater in order to be included (M=28.2, SD=1.80).

Table 4

Demographic information of participants. Standard deviations are represented in parentheses.

Group	N, Female	Age (Years)	Education (Years)	Aphasia Severity A, B	Native English Speakers	Ethnicity
Neurotypical	*15, 8*	*63.8 (10.75)*	*17.8 (1.97)*	-	*15*	*White (non-Hispanic), 11; African American or Black, 3; Asian, 1*
PWA	12, 7	*63.7 (8.26)*	*17.5 (3.52)*	*80.27 (14.36)*	*12*	*White (non-Hispanic), 8; Black or American, 4*

[A.] Western Aphasia Battery (Kertesz, 2007).
[B.] Maximal score of 100 indicates no impairment.

Procedures

Background Testing

All testing was completed in a quiet, well lit, minimally distracting, and accessible room in one session, lasting approximately sixty minutes. After obtaining informed consent, background data collection and inclusion screenings were completed. Following this, a confrontational naming task was administered to PWA. The confrontational naming task (M=0.84, SD=0.34) included twenty-action and twenty-object picture stimuli adapted from the Object and Action Picture Naming Battery matched for frequency and age-of-acquisition (Druks & Masterson, 2000). PWA participants were given up to thirty seconds to provide an answer on the confrontational naming task. If no verbal utterance was given after thirty seconds, the target was counted incorrect and participants were guided to the next trial. The object and action targets are included in Appendix A. In this study, all PWA were returning participants to the Aphasia Research Center and the WAB-R, had previously been administered. The WAB Aphasia Quotient (WAB-AQ) was gathered from each participant's record and included as a predictor of RQ3. The participants varied from moderate (n = 5) to mild (n = 7) aphasia severity (WAB-AQ: M=80.26, SD=14.36). The group included 3 PWA with anomic aphasia, 7 PWA with Broca's aphasia, and 2 PWA with transcortical motor aphasia. The naming abilities of participants varied greatly (M=0.84, SD=0.34), but aligned with WAB-R aphasia severity ratings.

Experimental Tasks

Four experimental tasks were administered to all participants: the pattern comparison, the Stroop task, the lexical decision ask, and the phoneme monitoring task. The presentation of computer tasks was randomized for each participant in order to minimize any order effects across computer tasks. Each task was created and administered using PsychoPy, a research experiment builder (Peirce, 2007). Three different computers were used during data collection, two desktop computers and one laptop. An equal number of participants, regardless of group status, were tested on each computer. The nonverbal response method required participants to respond by pressing a labeled button using his or her nondominant hand. This was used in order to control for possible unilateral paralysis in PWA. The experimental tasks are outlined in Table 5.

Table 5

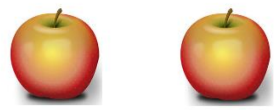
Experimental Task Overview. N refers to the number of trials.

Domain	**Experimental Task**	**Stimuli**	**Conditions**	**Dependent Variable**
Cognitive	Processing Speed *Pattern Comparison*	Picture Pairs (N = 180) (Figure 1)	Identical (N=90) Different by either color or parts (N=90)	RT
	Cognitive Control *Stroop*	Words in colored font (three colors – red, green, yellow) (N = 189)	Congruent (RED) (N=63) Incongruent (RED) (N=63) Neutral (PLAN) (N=63)	RT
Linguistic	Processing Speed *Lexical Decision*	Words and Nonwords (N =136)	Words (N=68) Nonwords (N=68)	RT
	Selection Control *Phoneme Monitoring*	Picture Pairs Actions/Objects (N = 51) (Figure 2)	Phoneme Present (N = 26) Phoneme Absent (N = 25)	RT

Pattern comparison for domain general processing speed. This task requires participants to compare two pictures side-by-side and make a same-different judgement. In the different condition, the two pictures differ either in terms of color (i.e. blue face versus a yellow face) or missing a part (i.e. tree versus a tree trunk) (Figure 1). The participants were introduced to the task, introduced to the computer layout, and trained on the task with twelve practice items. After the completion of practice items, participants were able to repeat practice items if requested, or advance to the trial items. Participants were asked to, as quickly as possible, make the decision whether the presented pictures are the same or different by pressing one of two keys on the keyboard that are labeled ‘yes’ or ‘no.’ Response time and response accuracy was collected.

Figure 1

Example stimuli from the pattern comparison task.

Condition	Stimuli
Identical	
Different by Color	
Different by Part	

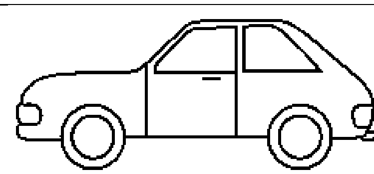
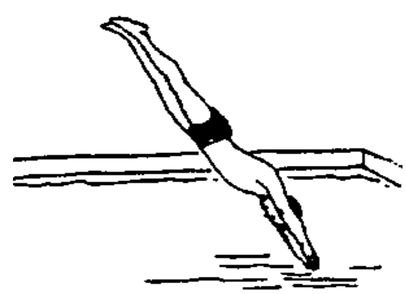
Stroop task for domain general cognitive control. In this task, each trial of stimuli presented had three possible conditions: 1) congruent - the written word matched the font color, 2) incongruent - the written word differed from the font color, or 3) neutral - the word “PLAN” was written in various font colors. The three font colors included in this Stroop task were red, green, and blue. In preparation for this experiment, a red, green, and blue sticker were placed on the computer keyboard arrow keys. Participants were asked to, as quickly as possible, press the arrow key on the keyboard that matched the font color. The participants were introduced to the task, introduced to the computer layout, and trained on seven practice items. After the completion of practice items, participants were able to repeat practice items if requested, or advance to the trial items. Response time and response accuracy was collected.

Lexical decision for domain specific lexical processing. In this task, a string of letters was presented on a computer screen, the letter string may be true English words or plausible nonwords. The participants were required determine whether the presented word was a true English word or a nonword. Nonwords followed orthographic and phonological constraints of the English language. A complete list of nonwords and true English words included in this study can be found in Appendix B. Participants were asked to, as quickly as possible, make the decision whether the presented word is a true English word or a nonword by pressing one of two keys, 'yes' for a true English word or 'no' for nonword. The participants were introduced to the task, introduced to the computer layout, and trained on four practice items. After the completion of practice items, participants were able to repeat practice items if requested, or advance to the trial items. Response time and response accuracy was collected.

Phoneme monitoring for a measure of domain specific linguistic selection control. Participants completed the phoneme monitoring task to assess domain specific linguistic selection control. In this task, a phoneme represented by its orthographic counterpart appeared on the screen, and the administrator produced the phoneme verbally. Second, a picture was presented on the computer screen and participants were asked to determine if the preceding phoneme given was present or absent in the main action or object in the picture stimulus. Example stimuli are included in Figure 2. The two conditions of this task are present and absent. In the phoneme present items, the target phoneme could be in word-initial, word-medial, or word-final position. All phoneme monitoring task items are listed in Appendix C. Participants were asked to, as quickly as possible, make the decision whether the presented picture has the target phoneme by pressing one of two keys on the keyboard labeled 'yes' when the phoneme is present, or 'no' when the phoneme is absent. The participants were introduced to the task, given a list written representation of the picture stimuli to familiarize themselves with the upcoming items, introduced to the computer layout, and trained on nine practice items. After the completion of practice items, participants were able to repeat practice items if requested, or advance to the trial items. Response time and response accuracy was collected.

Figure 2

Example stimuli from the phoneme monitoring task.

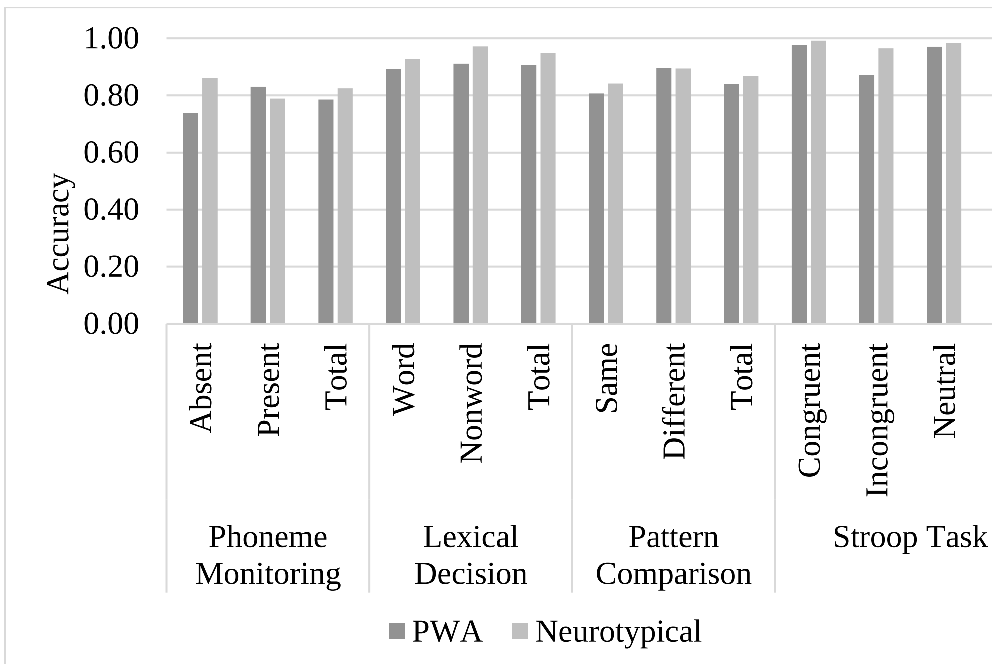
	Phoneme Monitored	Picture Stimuli
Example Noun	/r/ or /k/	
Example Action	/r/ or /k/	

After receiving feedback from the first participant, a post-test naming task was used to record the mental target the participant thought of during the phoneme monitoring task trials. Further, pictures with less than thirty-three percent naming agreement were replaced with pictures with greater than ninety-six percent naming agreement according to the IPNP. All pictures replaced are included in Appendix D. The post-test naming task was administered to all participants. The trials in which participants differed from the intended target were discarded from the data set before analysis. After testing all participants, an item analysis was completed, and it was found that not one target that had less than sixty percent accuracy across all participants. Therefore, there were no additional targets replaced. Lower accuracy during this task came from PWA failing to name the appropriate target, and a select few neurotypical controls who reported related vocabulary items. For example, '*Santa Clause'* instead of the target '*Beard.'*

Chapter 4: Results

Experimental Results

Table 6
Accuracy for experimental tasks



The main outcome measure for all experimental tasks is the response time for correctly responded trials. An alpha value of 0.05 was used to determine statistical significance. First, participant responses for all tasks were cleaned by removing data of incorrect trials. Second, any trials identified as incorrectly targeted in the phoneme monitoring task were removed. The Stroop effect was calculated by subtracting congruent trial RTs from the incongruent trial RTs. Statistical Package for Social

Sciences (SPSS version 24 International Business Management) was used to conduct statistical analyses. A separate generalized linear mixed effects analysis with group as the fixed effect and items and participants as random effects (intercept included) was used for each experimental task (Baayen, Davidson & Bates, 2008). For the third research question, a linear regression analysis was completed with the enter method. The reaction times of the four tasks are presented in Table 7 and the results of the generalized mixed effects analysis are reported in Table 8. Accuracy data for each participant did not fall below the 75% correct responses inclusion criteria. Participant's individual accuracy can be found in Appendix E. A comparison of accuracy showing group averages on experimental tasks can be found in Table 6.

Table 7
Results of Reaction Times (RT) for all computer tasks – represented in milliseconds

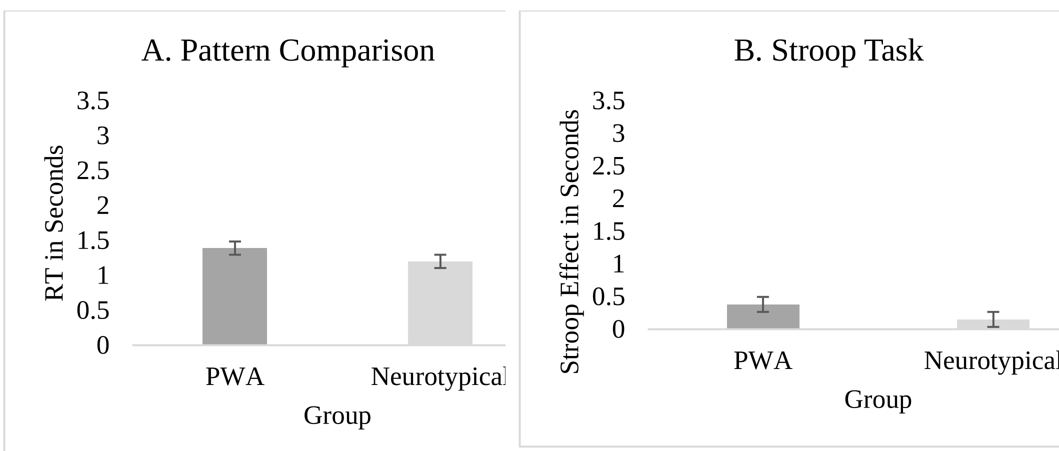
	PWA (N=12)		**Neurotypicals (N=15)**	
	Mean	*SD*	*Mean*	*SD*
Pattern Comparison Task				
Same	1,210	330	950	340
Different	1,280	250	1,140	250
Total	1,390	280	1,200	280
Stroop Task				
Congruent	1,400	400	960	190
Incongruent	1,790	810	1,110	270
Neutral	1,320	340	910	180
Stroop Effect	380	570	150	100
Lexical Decision Task				
True English Words	1,830	370	1,450	210
Nonwords	1,840	380	1,620	320
Total	1,830	370	1,530	260
Phoneme Monitoring Task				
Phoneme Present	2,500	740	1,740	440
Phoneme Absent	3,360	1,060	2,640	940

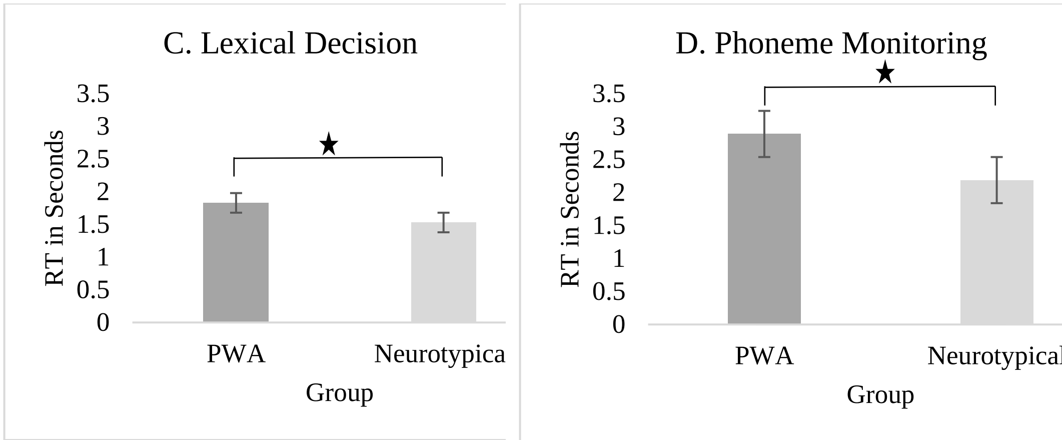
Total	2,890	900	2,190	660

The generalized linear mixed analyses for all experimental tasks looked for between group significant differences, the results are as follows: *Pattern comparison task*, nonsignificant differences between the two groups ($F(1, 3,459) = 2.68$, $p > 0.10$); *Stroop task,* significant differences between groups, participants, items, and conditions $F(1, 4673)= 12.63$, $p > 0.000$); *the Stroop effect (cognitive control*), nonsignificant performance between groups ($F(1, 25) = 2.27$, $p > 0.17$); *lexical decision task,* significant differences between groups ($F(1, 3534) = 4.59$, $p > 0.03$); *phoneme monitoring task*, significant differences between groups ($F(1, 1,500) =12.07$, $p < 0.001$).

Figure 3

Group estimated means for all experimental tasks.





★ Marks statistical significance between groups as determined at the 0.05 level.

Table 8

Results of the generalized linear mixed model analysis.

	Coef β	**SE (β)**	**t**
Pattern Comparison Task			
Fixed Effect: Group			
Intercept	1.39	0.09	16.05**
Group (Neurotypical)	-0.19	0.11	0.10
Random Effects: Items & Participants			
Residual Variance	0.44	0.01	33.96
Stroop Task (Raw Data)			
Fixed effects: Group & Condition			
Intercept	1.20	23981.26	0.000
Group (Neurotypical)	neg0.15	23891.26	0.000
Condition	0.42	23981.25	0.000
Random Effects: Participant & Item			
Residual Variance	0.09	0.001	149.51
Stroop Effect (Cognitive Control)			
Fixed effects: Group			
Intercept	0.38	0.12	3.25**
Group (Neurotypical)	neg0.22	0.16	0.17
Random Effects: Participant & Item			
Residual Variance	0.09	0.001	149.51
Lexical Decision Task			
Fixed Effect: Group			
Intercept	1.83	0.10	17.98
Group (Neurotypical)	neg0.28	0.13	neg2.14**
Random Effects: Participant & Item			
Residual Variance	0.23	0.01	18.95
Phoneme Monitoring Task			
Fixed Effect: Group			
Intercept	2.88	0.19	14.72
Group (Neurotypical)	neg0.64	0.18	neg3.47
Random Effects: Participant & Item			
Residual Variance	1.49	0.11	13.52

**Statistically significant at the 0.05 level.

To address the RT data from the Stroop task (RQ2), two linear mixed model analyses were completed. The first analysis used the Stroop raw data and was completed to assess the variability between items, participants, and groups in the Stroop task. The model was significant at the 0.000 level. The Stroop task raw data response times (Table 7) and accuracy data (Appendix E) reflect individual variation found amidst the generalized linear mixed model analysis (Table 8).

The third research question (word retrieval and the relationship between processing speed, linguistic processing speed, cognitive control, and aphasia severity) was addressed using a linear regression analysis with phoneme monitoring RT as the dependent variable and processing speed RT, Stroop effect, lexical decision RT, and WAB-AQ as the predictors. All predictors were simultaneously entered into the model. All twelve PWA and fifteen neurotypical controls were included in this analysis. A simple linear regression was calculated to predict phoneme monitoring RT based on lexical decision RT WAB-AQ, pattern comparison RT, and Stroop effect RT. All twelve participants were included in this analysis. The PWA group analysis found a nonsignificant regression equation ($F(4, 7)=1.13$, $p <0.42$), with an R^2 of 0.39. Participants predicted RT on the phoneme monitoring task is equal to 0.63 + 0.23 (pattern comparison RT) when word retrieval is measured by the pattern comparison task. Phoneme monitoring RT increased 0.23 seconds for each degree of lexical decision RT. Participants predicted RT on the phoneme monitoring task is equal to 0.63 + 0.04 (Stroop effect) when word retrieval is measured by the pattern comparison task. Phoneme monitoring RT increased 0.04 seconds for each degree of the Stroop effect RT. Participants predicted RT on the phoneme monitoring task is equal to 0.63 + 0.27 (lexical decision) when word retrieval is measured by the lexical decision task. Phoneme monitoring RT increased 0.27 seconds for each degree of the lexical decision task RT. Participants predicted RT on the phoneme monitoring task is equal to 0.63 + 0.39 (WAB-AQ) when word retrieval is measured by aphasia severity. Phoneme monitoring RT increased 0.39 for each degree of aphasia severity (WAB-AQ).

Table 9
Results of the linear regression analysis.

	Coef β	SE (β)	t
Word Retrieval in PWA			
Target: Phoneme Monitoring RT			
Constant	neg1.398	2.44	neg0.57
Pattern Comparison	1.59	1.17	1.35
Stroop Effect	0.41	0.48	0.86
Lexical Decision	neg1.22	1.13	neg1.07
Aphasia Severity (WAB AQ)	0.05	0.30	1.70
Word Retrieval in Neurotypicals			
Target Phoneme Monitoring RT			
Constant	0.45	0.62	0.73
Pattern Comparison	1.53	0.58	2.63**
Stroop Effect	2.80	0.99	2.82**
Lexical Decision	neg0.32	0.60	neg0.53

**Statistically significant at the 0.05 level.

A simple linear regression was calculated to predict phoneme monitoring RT based on lexical decision RT, pattern comparison RT, and Stroop effect RT. All fifteen neurotypical controls were included in this analysis. The neurotypical control group analysis found a significant regression equation ($F(3,11)=9.73$, $p > 0.002$), with an R^2 of 0.73. Participants predicted RT on the phoneme monitoring task is equal to 0.46 + 1.54 (pattern comparison RT) when word retrieval is measured by the pattern comparison task. Phoneme monitoring RT increased 1.54 seconds for each degree of lexical decision RT. Participants predicted RT on the phoneme monitoring task is equal to 0.46 + 2.80 (Stroop effect) when word retrieval is measured by the pattern comparison task. Phoneme monitoring RT increased 2.80 seconds for each degree of the Stroop effect RT. Participants predicted RT on the phoneme monitoring task is equal to 0.46 + -0.33 (lexical decision) when word retrieval is measured by the lexical decision task. Phoneme monitoring RT increased -0.33 seconds for each degree of the lexical decision task RT.

As the original model was not significant after running the first statistical analysis for the third research question, it was deemed unclear whether the lack of significance was due to the population of PWA or due to the lack of statistical significance in general. Three PWA (AP120, AP129, AP132) had WAB-AQ *mild* WAB-AQ scores (WAB-AQ > 90) indicating minimal impairment. As it is possible these participants functioned like the neurotypical older control groups, it is possible that statistical significance would be found when excluding these the data of these participants in the analysis. An exploratory analysis was completed with nine PWA and fifteen neurologically healthy controls' data. A simple linear regression was calculated to predict phoneme monitoring RT based on lexical decision RT, WAB-AQ, pattern comparison RT, and Stroop Effect RT. Even with the mildly aphasic participants excluded, a nonsignificant regression equation was found ($F(4,4) = 0.87$, $p > 0.55$, with an R^2 of 0.466. Participants predicted RT on the phoneme monitoring task is equal to -0.46 + 1.75 (pattern comparison RT) when word retrieval is measured by the pattern comparison task. Phoneme monitoring RT increased 1.75

seconds for each degree of lexical decision RT. Participants predicted RT on the phoneme monitoring task is equal to -0.46 + 0.57 (Stroop effect RT) when word retrieval is measured by the Stroop effect. Phoneme monitoring RT increased 0.57 seconds for each degree of Stroop effect RT. Participants predicted RT on the phoneme monitoring task is equal to -0.46 + -0.94 (lexical decision RT) when word retrieval is measured by the lexical decision task. Phoneme monitoring RT increased -0.94 seconds for each degree of lexical decision RT. Participants predicted RT on the phoneme monitoring task is equal to -0.46 + 0.03 (WAB-AQ) when word retrieval is measured by aphasia severity. Phoneme monitoring RT increased 0.03 for each degree of aphasia severity (WAB-AQ).

Chapter 5: Discussion

Overview

This study had three goals, to compare domain general measures, pattern comparison task and Stroop task, in PWA and neurotypical controls. Meanwhile researching if domain general processing speed and domain general cognitive control RTs predict word retrieval RTs. It was hypothesized that PWA would have longer RTs than neurotypical controls for all measures. Further, it was hypothesized that word retrieval RTs would be influenced by domain general cognitive control and domain general processing in PWA. This study found that PWA did not statistically differ in domain general processing speed or domain general cognitive control, rather PWA only had statistical differences in domain specific linguistic measures when compared to neurotypical controls. As for predictors of word retrieval RTs, our model was nonsignificant for PWA indicating that domain general processing and domain general cognitive control did not predict word retrieval RTs. In neurotypical controls, the model was significant indicating that domain general processing speed and domain general cognitive control predict word retrieval RTs.

Processing speed and its relationship with word retrieval

Overall, this study exists as a new area of research in PWA, examining the relationship between domain general processing speed and word retrieval. The findings of this study indicate that, while RTs are slower in PWA compared to controls, this RT latency is nonsignificant. This finding yielded new insight into the domain general processing speed of PWA when measured by the pattern comparison task.

Since domain general processing speed, as defined by Salthouse (1994) references a finite amount of processing speed. It was surprising to find that PWA did not have a correlation between domain general processing speed and word retrieval. As PWAs have increased word retrieval RTs, it would have been logical for domain general processing speed to act as one piece to word retrieval RT latencies. This, however, was not the findings from this study. This unexpected performance by PWA is noteworthy because other disorders with word retrieval deficits tend to be predicted by domain general deficits (Savage, McBreen, Genesee, Erdos, Haigh, & Nair, 2018). Rather, the nonsignificant findings of this research support that aphasia is primarily defined by language impairments (McNeil, Pratt, Dickey, & Fassbinder, 2011; Papathanasiou & Coppens, 2017; & Schwartz et al., 2009).

Meanwhile the significant difference in neurotypical controls indicate that domain general processing speed does play role in word retrieval in neurotypical adults. Domain specific processing, as in the pattern comparison task, measures simple attention and concentration, which are required through the task (Carlozzi et al. 2014). It is likely that a significant difference was found within the neurotypical controls because older adults have highly refined domain general processing systems. In PWA, this was not seen because domain specific language impairments were present and as there is only a limited capacity of processing speed, as defined by

Salthouse (1994), that could be used to compensate for domain specific language impairments.

As the nonsignificant differences between the PWA group and the neurotypical control group was surprising, there are several explanations that describe these findings. One, previous research that has suggested processing speed to be impaired in stroke used participants within 3 months post onset of stroke, had right ischemic (41%) or hemorrhagic (59%) origins, right sided (43%), left sided (36%), and bilateral (20%) impairments. (Loranger, et al., 2000). Another study also used participants within 6 months onset of Stroke (Rasquin, et al., 2002). Su. et al. (2015) had 67% right hemispheric lesions, and 23% left hemispheric lesions. The participants in this study all were diagnosed with aphasia, therefore indicating a lesion in the left hemisphere.

A second explanation as to why this study did not find significant differences in processing speed as past research suggested is based on the method of measurement. Loranger et al. (2000) used a combination of standardized assessments (CPT) and a stopwatch use of reaction times. Rasquin et al., (2002) also used an imprecise measure of standardized assessments and stopwatch recording times to calculate cognitive function. Su. et al (2015) used the SDMT Oral version to assess processing speed, which is another imprecise measure compared to the pattern comparison task in this study.

In the current study, the pattern comparison ask was included in the experimental tasks as it is a simple task that uses the reaction times of pressing a button, it additionally is recommended by the NIH toolbox as a valid assessment of processing speed. The implications of using a simple processing speed task, and PWA greater than 6 months post onset suggests that the results of this study may be a better representation of the domain general processing speed in comparison to past studies. Additionally, all stroke studies mentioned in this research had predominantly right-hemisphere lesions. This suggests that processing speed deficits may only be seen in right-hemispheric strokes, and as aphasia is defined as a left-hemisphere lesion, it is possible that location of the lesion is the most predictive of impaired processing speed.

Cognitive Control in PWA

Based on pilot data (Faroqi-Shah, et al., 2016) it was expected that PWA would have statistically significant RT latencies compared to neurotypical controls as measured by the Stroop effect (Caplan et al., 2011; Faroqi-Shah et al., 2016**;** Hoffman, Jefferies, Haffey, Littlejohns, & Lambon Ralph, 2013; Pompon et al., 2013; Sung et al., 2011). Using the Stroop effect, even as a true measure of interference and inhibition control, did not align with predictions. As statistical significance was not found, we see that while others have suggested PWA would have impaired cognitive control (Dash & Kar, 2014; Faroqi-Shah et al., 2016; Kuzmina & Weekes, 2017; Manie, et al., 2018; Pompon et al., 2013), those suggestions were not corroborated in this study.

Overall, the results of the generalized linear mixed model did not find significant group differences in RT as was expected. There are several rationales that explain the lack of a deficit found by previous researchers (Pompon et al., 2015;

Faroqi-Shah et al., 2016). The first rationale could be due to the Stroop effect calculated in this experiment. Typically, the Stroop effect is calculated by subtracting the neutral RT trials from the incongruent RT trials. This study calculated the Stroop effect of incongruent trials minus congruent trials. The second rationale would be the severity of aphasia of PWA included in this study. The PWA included in this study had moderate to mild aphasia severity (WAB-AQ= 80.27, SD= 14.36). While a possible explanation Faroqi-Shah et al. (2016) included PWA with similar severity to the current study (WAB-AQ M=75.5, SD=15.03), and Pompon et al. (2015) did not report the WAB-R scores of individual participants but stated in the study's inclusion criteria that all participants were aphasic as described by McNeil and Pratt (2001). It is possible that Pompon et al. (2015)'s participants differed than the PWA included in this study and is a confounding explanation as to why this study did not have significant differences compared to neurotypical controls.

Last, while there were no significant differences between group RTs, there was great variability between the PWA RT groups (congruent M=1,400 ms, SD=400 ms; incongruent M=1,790 ms, SD=810 ms; neutral M=1,320 ms, SD=340 ms; Stroop effect M= 380 ms, SD=570 ms) that was not seen in the neurotypical group (congruent M=960 ms, SD=190 ms; incongruent 1,110 ms, SD= 270 ms; neutral M=910 ms, SD=150 ms, Stroop effect M=150 ms, SD= 100 ms). This great variability between the group's performance, while nonsignificant, indicates that there are differences among the two groups, rather, there is something within the PWA group that adds a certain level of variability. Two rationales for the variability come from posited poor inhibition known in PWA (Pompon et al., 2015; Faroqi-Shah et al., 2016) or lexical access deficits (Howard & Gatehouse, 2006; Levelt & Indefrey, 2004; Papathanasiou, & Coppens, 2017; Shivabasappa, & Krishnan, 2011). In many previous studies, PWA have been found to have a lack of inhibition based on the lesion causing PWA, specifically within the linguistic domain and with the impaired monitoring systems that are used in successful word retrieval. While this study did not find an impairment in inhibition, or domain general cognitive control, the results of this study indicate that perhaps with a larger sample size of PWA an inhibition deficit may have been found. A second rational for the variability found within the raw data is that, as lexical access deficits are present in PWA (Howard & Gatehouse, 2006; Papathanasiou, & Coppens, 2017; Shivabasappa, & Krishnan, 2011), it is possible that PWA included in this study have lexical access deficits and therefore were unable to demonstrate a true Stroop effect, and lack of cognitive control, due to confounds of the measure of cognitive control. To control this PWA were required to pass a color-to-text screener and the WAB-R single word-reading level. However, even though PWA passed these screening measures to be included, the color-to-text screener had significant delays in RT for the PWA population (M=1,950 ms; SD=476 ms). While the PWA were accurate and passed the screener, there were latencies noted in this screener which indicates it takes PWA a long amount of time to complete this task. These latencies could indicate that PWA included in this study do have lexical access deficits as represented by increased RT.

Predictors of Word Retrieval

Table 10

Predictors of word retrieval as measured by the phoneme monitoring task.

The values represent unique variance (β) of the regression model. The numbers in parentheses are the total variance of the model (R^2).

	Group	
Predictors	**PWA (n=12)**	**Neurotypical (n=15)**
	(0.39)	(0.85**)
Pattern Comparison Task	ns	0.77**
Stroop Effect	ns	0.72**
Lexical Decision Task	ns	0.52*
Aphasia Severity (WAB AQ)	ns	-

**Statistically significant at the 0.01 level.

*Statistically significant at the 0.05 level.

While the results of our word retrieval model were not predicted by domain general processing speed and domain general cognitive control for PWA, an interesting finding for the PWA population is within the linguistic domain. Table 11 shows the results of the nonparametric Spearman's rho analysis that found PWA's aphasia severity was strongly correlated with the lexical decision RT. This finding supports and emphasizes that the aphasia is characterized by a deficit within the linguistic domain.

Table 11

Results of the Spearman's rho analysis

CORRELATIONS

		Stroop Effect	Phoneme Monitoring	Pattern Comparison	Lexical Decision	WAB-AQ
Neurotypical	Stroop Effect	-	.72**	0.44	0.31	n/a
	Phoneme Monitoring	.72**	-	.77**	.52*	n/a
	Pattern Comparison	0.44	.77**	-	.77**	n/a
	Lexical Decision	0.31	.52*	.77**	-	n/a
PWA	Stroop Effect	-	0.04	0.07	0.11	-0.04
	Phoneme Monitoring	0.04	-	0.23	0.27	0.39
	Pattern Comparison	0.07	0.23	-	0.10	-0.20
	Lexical Decision	0.11	0.27	0.10	-	.77**
	Aphasia Severity	-0.04	0.39	-0.20	.77**	-

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The results of the analysis indicated that PWA's word retrieval was not predicted by processing speed and cognitive control tasks. Rather, the WAB-AQ and lexical decision RT coefficient indicated a negative relationship with increased lexical decision latency and a lower WAB score (indicating the worse aphasia severity) predicting the phoneme monitoring RTs. This is not a new finding to the literature and supports that aphasia is primarily characterized by a language specific impairment (McNeil, Pratt, Dickey, & Fassbinder, 2011; Papathanasiou & Coppens, 2017; & Schwartz et al., 2009). As some researchers have already paired processing speed training and word retrieval training in PWA (Manie, et al., 2018), the hope of this research was to find a component, cognitive control or processing speed, that was predictive in word retrieval. As this was not the case, the mystery of word retrieval latencies in PWA remains. Rather, traditional word retrieval treatment such as strengthening lexical access, building semantic features, and practicing phonological mapping would provide the most effective therapy for word retrieval deficits as supported by this study.

Recommendations

Within this experiment design, the phoneme monitoring task was designed to act as a measure of word retrieval. While this was primarily true for the nouns within the task, there was great ambiguity amongst several of the verb targets (i.e. pay, miss, & crawl). As verbs had generally poor imageability, future research should be done to identify the amount of cognitive control utilized in both nouns and verbs. As the first four participants tested were adamantly against some trials in the task, we built in a picture naming task. After completing the picture naming task, participants were asked to name each target with their ideal target. Several items were consistently ambiguous to participants, while other participants had idiosyncratic responses. For that reason, the data from these idiosyncratic and ambiguous trials was removed from the data before statistical analysis was completed. In the future, this task should be updated with picture targets that have high agreement levels of imageability (1.00). While the phoneme monitoring task was an ideal nonverbal measure of word retrieval, it did not contain many trials. The phoneme monitoring task had the least amount of trials (Version 1, N=26; Version 2, N=51), compared to the pattern comparison task (N=180), lexical decision (N=136), and Stroop task (N=189). Additionally, the participants included in this study all had low levels of aphasia severity (M = 80.27, SD = 14.36). If future studies should replicate the methodology of the current study, it would be best for the aphasia literature to include a diverse population of PWA. The final limitation of this study would be the non-timed version of confrontational naming task that was used as the word retrieval baseline. The phoneme monitoring task was used as a nonverbal measure of word retrieval, the dependent variable in this task was the response time. The confrontational picture naming task did not record the response time for each measure. In future studies, a timed confrontational naming task should be administered in order to act as a comparison of response times on the phoneme monitoring.

Conclusion

In the present experiment, PWA and neurotypical controls completed computer tasks to measure primarily processing speed, cognitive control, and word retrieval. The first aim of the research, identifying processing speed in PWA and controls, found that while PWA had greater RT latency, the difference was nonsignificant compared to neurotypical controls. The second aim of the research, identifying cognitive control abilities in PWA and controls, again found a nonsignificant difference in RT latency compared to neurotypical controls. The third, and last, aim of this research was to identify if cognitive control (the Stroop effect) and processing speed (the pattern comparison task) RT predicted our nonverbal word naming assessment (the phoneme monitoring task). This third aim was supported in neurotypical group. The results of our study found that both processing speed and cognitive control RT predicted word retrieval performance. This supports that in non-brain damaged persons, processing speed and cognitive control are used in word retrieval. However, in the PWA population, processing speed RT and cognitive control RT did not predict word retrieval performance. Rather, it was supported that aphasia severity and lexical decision RT predicted word retrieval performance. This supports that the biggest impairment in PWA is language specific. This provides strong new evidence for word retrieval in neurotypical controls, processing speed and cognitive control are fundamentally predictive in word retrieval. Meanwhile, this research supports past aphasic research that suggests the primary, and most predictive, impairment in aphasia is a language impairment.

Appendix A

Confrontational Naming Baseline Stimuli

Appendix A includes the list of picture targets that were used to assess PWA's accuracy during verbal confrontational naming tasks. A confrontational naming baseline was gathered at the beginning of each participant's session. Each participant was given up to thirty seconds to recall the target, after thirty seconds the participants were guided to the next picture target and the unrecalled target was marked incorrect. The object and action pictures are frequency-matched, and age-of-acquisition matched.

Actions	**Objects**
1. Barking	1. Pyramid
2. Juggling	2. Pram
3. Tickling	3. Camel
4. Skating	4. Waitress
5. Yawning	5. Kettle
6. Weaving	6. Tray
7. Kneeling	7. Curtain
8. Floating	8. Plug
9. Shaving	9. Candle
10. Biting	10. Envelope
11. Ringing	11. Tongue
12. Sinking	12. Camera
13. Dreaming	13. Bus
14. Sliding	14. Angel
15. Cooking	15. Cow
16. Shooting	16. Weight
17. Pushing	17. Finger
18. Singing	18. Bridge
19. Eating	19. Square
20. Smiling	20. Ball

Adapted from An Object and Action Naming Battery (Druks and Masterson, 2000)

Appendix B

Lexical Decision Task Stimuli

Nonword Targets		True English Words	
Bimering	drilking	licking	gasping
bekefing	braping	winking	speaking
flurping	sorping	tying	screaming
biming	buting	knitting	holding
demaving	clarping	talking	tickling
daroting	bapping	drinking	yelling
jilking	degaking	frowning	pinching
gapeting	darkoring	wiping	gripping
stipping	kaneking	glancing	slapping
pinoping	binasing	washing	stuttering
dibaming	jilking	folding	pinching
blopping	dasoging	squinting	smirking
kidaling	golaving	snipping	nodding
drilking	baping	scratching	knocking
puzing	binasing	wringing	knitting
dekising	daliding	digging	weeping
kosofing	lerping	chomping	scratching
beroting	gitining	lifting	sucking
kaneking	vemming	hitting	nodding
flurping	plabing	chopping	tickling
akolling	plurping	peeling	smirking
diviking	batising	drawing	clutching
dafeshing	tafading	poking	looking
beeling	balimoting	talking	whispering
bisobing	jeeging	speaking	lifting
gelidding	biveting	sighing	sniffing
bogating	melping	murmuring	snatching
pamusing	doding	chewing	smiling
daroting	blaiting	patting	glancing
tafading	bumitting	hacking	writing
fissing	belosing	biting	shrieking
preaming	golaving	drinking	peeling
garolling	garolling	sawing	frowning
felshing	plurping	staring	grinning

Appendix C

Phoneme Monitoring Task Object and Action Stimuli: Picture stimuli included in the phoneme monitoring task were adapted from the International Picture Naming Project (IPNP). Appendix C lists each of the practice, object, and action targets.

Practice Targets	**Object Targets**	**Action Targets**
Walk	Ant	Bark
Sleep	Bat	Bite
Cook	Bear	Chain
	Beard	Chew
	Bell	Clap
	Bride	Cough
	Car	Crawl
	Cheese	Cry
	Egg	Cut
	Fish	Dance
	Fork	Dig
	Frog	Dive
	Glove	Dry
	Heart	Laugh
	Horse	Miss
	Key	Paint
	Lips	Pay
	Lock	Read
	Moon	Run
	Mouse	Serve
	Queen	Shave
	Spoon	Squeeze
	Tent	Swim
	Tree	Swing
	Wheel	Wave
		Write

Appendix D

Phoneme Monitoring Stimuli: Targets and Norms

Adapted from IPNP

This table includes the targets in the phoneme monitoring task that were replaced part way through the task. The column 'Version 1: Norms' reflects the agreement of the target as defined by the International Picture Naming Project (IPNP). Twelve participants completed version 1, the remaining participants (n=14) completed version 2.

Version 1: Target	**Version 1: Norms**	**Version 2: Target**	**Version 2: Norms**
Write	.56	Surf	1.0
Wave	.36	Blow	1.0
Serve	.57	Kiss	1.0
Pay	.69	Smoke	1.0
Miss	.34	Iron	1.0
Laugh	.28	Climb	.96
Dry	.34	Eat	.96
Cough	.34	Kick	.96
Chew	.35	Push	.96

Adapted from IPNP, (Brysbaert & New, 2009).

Appendix E

Accuracy data from all experimental tasks

Persons With Aphasia

			AP115	*AP117*	*AP119*	*AP120*	*AP127*	*AP128*	*AP129*	*AP132*	*AP87*	*AP88*	*AP92*	*AP93*
Phoneme Monitoring Task	Condition	Absent	0.73	0.83	0.71	0.90	0.65	0.90	0.77	0.72	0.70	0.67	0.63	0.65
		Present	0.77	0.71	0.77	0.77	0.90	0.90	0.77	0.78	0.90	0.90	0.93	0.84
		Total	**0.75**	**0.77**	**0.75**	**0.84**	**0.77**	**0.90**	**0.77**	**0.76**	**0.80**	**0.79**	**0.78**	**0.75**
Lexical Decision Task	Condition	Word	0.91	0.96	0.90	0.94	0.78	0.97	0.88	0.84	0.85	0.93	0.84	0.93
		Nonword	0.81	0.99	0.96	0.99	0.71	1.00	0.99	0.91	0.99	0.91	0.76	0.93
		Total	**0.86**	**0.97**	**0.93**	**0.96**	**0.80**	**0.99**	**0.93**	**0.88**	**0.92**	**0.92**	**0.80**	**0.93**
Pattern Comparison Task	Condition	Different	0.94	0.90	0.89	0.92	0.92	0.87	0.92	0.87	0.90	0.94	0.87	0.81
		Same	0.83	0.82	0.79	0.77	0.82	0.79	0.74	0.74	0.85	0.89	0.80	0.83
		Total	**0.88**	**0.86**	**0.84**	**0.84**	**0.75**	**0.83**	**0.83**	**0.81**	**0.88**	**0.91**	**0.84**	**0.82**
Stroop Task	Condition	Incongruent	0.87	0.95	0.98	0.98	0.82	1.00	0.98	1.00	0.85	0.17	0.93	0.92
		Congruent	0.92	1.00	1.00	1.00	0.87	1.00	0.98	1.00	0.97	1.00	1.00	0.98
		Neutral	0.95	1.00	1.00	1.00	0.77	1.00	0.98	1.00	0.98	1.00	0.97	1.00
		Total	**0.91**	**0.98**	**0.99**	**0.99**	**0.82**	**1.00**	**0.98**	**1.00**	**0.93**	**0.72**	**0.97**	**0.97**

Neurologically Healthy Controls

			AN105	**AN106**	**AN107**	**AN108**	**AN109**	**AN122**	**AN208**	**AN209**	**AN210**	**AN211**	**AN212**	**AN213**	**AN42**	**AN80**	**AN82**
Phoneme Monitoring Task	Condition	Absent	1.00	0.93	0.76	0.90	0.87	0.67	0.97	0.77	0.83	0.77	1.00	0.93	0.90	0.87	0.77
		Present	0.88	0.69	0.75	0.65	0.84	0.90	0.58	0.94	0.84	0.90	0.91	0.71	0.61	0.81	0.84
		Total	**0.94**	**0.81**	**0.76**	**0.77**	**0.85**	**0.79**	**0.77**	**0.85**	**0.84**	**0.84**	**0.95**	**0.82**	**0.75**	**0.84**	**0.80**
Lexical Decision Task	Condition	Word	0.97	0.97	0.97	0.99	0.99	0.99	0.76	0.94	0.66	0.97	1.00	0.84	0.91	0.96	1.00
		Nonword	1.00	0.99	1.00	0.94	1.00	0.99	1.00	0.99	1.00	0.97	0.97	0.93	0.84	0.97	1.00
		Total	**0.99**	**0.98**	**0.99**	**0.96**	**0.99**	**0.99**	**0.88**	**0.96**	**0.83**	**0.97**	**0.99**	**0.88**	**0.88**	**0.96**	**1.00**
Pattern Comparison Task	Condition	Different	0.90	0.87	0.94	0.92	0.94	0.94	0.89	0.89	0.79	0.83	0.89	0.95	0.86	0.90	0.90
		Same	0.86	0.82	0.85	0.83	0.85	0.89	0.80	0.80	0.85	0.76	0.86	0.85	0.85	0.86	0.88
		Total	**0.88**	**0.84**	**0.89**	**0.88**	**0.89**	**0.91**	**0.84**	**0.84**	**0.82**	**0.79**	**0.88**	**0.90**	**0.85**	**0.88**	**0.89**
Stroop Task	Condition	Incongruent	0.97	0.97	0.98	0.98	0.93	0.92	1.00	0.97	0.93	0.92	1.00	1.00	0.93	0.97	1.00
		Congruent	0.98	1.00	1.00	1.00	0.98	1.00	1.00	1.00	1.00	1.00	0.97	1.00	0.95	1.00	1.00
		Neutral	1.00	1.00	1.00	1.00	1.00	0.98	1.00	0.98	0.97	0.98	0.97	1.00	0.95	0.97	0.97
		Total	**0.98**	**0.99**	**0.99**	**0.99**	**0.97**	**0.97**	**1.00**	**0.98**	**0.97**	**0.97**	**0.98**	**1.00**	**0.94**	**0.98**	**0.99**

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