Use of Verbal Mediation to Facilitate Working Memory Performance in Persons with Aphasia

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Dedication

This thesis is dedicated to Jack Goldstein, stroke survivor and friend.

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Abstract of Thesis

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Introduction: We use language to communicate with one another and with ourselves. Using self-directed inner language to guide our behavior is referred to as verbal mediation. The impact of aphasia on communication between people has been widely studied, while the impact of aphasia on verbal mediation has not. This study investigated the relationship between lexical access and performance on a working memory task (n-back) to determine if Persons with Aphasia (PWA) use intact word retrieval (verbal mediation) to support working memory. An articulatory suppression condition was also conducted to determine if disruption of the working memory phonological loop impairs the use of verbal mediation. ***Method:*** Four PWA and four Neurologically Intact (NI) participants completed n-back tasks varying in load (n=0, 1, 2) and stimulus type (readily nameable/ high frequency objects, unnameable/ low frequency objects, blocks) under both baseline and articulatory suppression conditions. Data analysis explored the impact of these variables within and across participants and groups. ***Results:*** The PWA group performed significantly worse than the NI group for nine n-back tasks. In five instances where a significant difference was found among the load levels, the significant difference was in the direction of n=0 > n=2. None of the comparisons among the stimulus types or between the conditions was significant. Comparisons between individual PWA scores and the mean NI scores yielded 23 significant differences, with PWA performing significantly worse. ***Discussion:*** The PWA group presented with decreased WM capacity when compared to the NI group, particularly for 1-back tasks. For both groups, WM capacity was impaired in a predominantly load-dependent manner, with significant differences in the direction of n=0 > n=2. Overt naming ability did not align with WM performance. Implementation of the articulatory suppression condition did not impact WM performance. A WM deficit may contribute to language-processing impairments in the PWA group. If PWA are attempting to use verbal mediation to guide their thoughts and behavior, their ability to use covert language may be impacted by concomitant WM deficits and degraded performance associated with subtle changes in processing load. Intact word retrieval may not support the use of verbal mediation to facilitate working memory performance; however, PWA may employ the visuospatial sketchpad to support WM when lexical retrieval fails. Results also align with anecdotal evidence from PWA that they have access to inner language even when they have difficulty communicating with others.

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Chapter 1: Introduction

Aphasia is an impairment of language that results from focal damage to the brain, usually the cortex of the left cerebral hemisphere. The overt manifestations of aphasia are well documented (Raymer, 2005), and include deficits in both receptive and expressive language functions. Perhaps the most common deficit observed among Persons with Aphasia (PWA) is impairment of lexical access. PWA routinely encounter difficulty in retrieving specific words from their lexicon. Most models of lexical retrieval posit two stages – retrieval of lexical-semantic representations (lemma) and retrieval of phonological word forms (Dell & O'Seaghdha, 1992; Levelt, 1999). Anomia, or word-retrieval difficulty, can manifest itself in speech production errors such as semantic paraphasias (e.g., saying “cat” for dog) or phonemic paraphasias (e.g., saying “ragon” for wagon). Substantial evidence of this clinical sign is found in the literature that characterizes PWA speech during conversation and performance on confrontation naming tasks (Raymer, 2005).

As noted above, the overt; i.e., communicative, signs of aphasia are apparent and well documented. What is far less apparent, and less well examined, is the ability of PWA to use language covertly to support working memory (WM) and other cognitive functions. Do PWA experience the same limitations in using language to facilitate and guide their behavior covertly as they encounter when using language overtly to communicate? Do they experience the same types of difficulty employing verbal mediation?

Verbal mediation is self-directed private language that helps facilitate and guide behavior (Vygotsky, 1986). It can be overt (vocal) or covert (subvocal), and can be conscious or unconscious. We may use verbal mediation to complete daily activities, such as when we employ it to hold onto a mental shopping list or follow steps to cook a favorite meal. Studies of Neurologically Intact (NI) individuals have demonstrated that verbal mediation in the form of deliberate “think aloud” strategies and self-explanation significantly predicts performance on a variety of problem solving and memory-related tasks (Chi, de Leeuw, Chiu, & LaVancher, 1994; Cole & Pheng, 1998). It is well established that linguistic encoding (including lexical-semantic and phonological encoding) enhances recall of information in short-term memory (STM) tasks. Silverberg and Buchanan (2005) found that verbalizing novel figure designs facilitated memory in a subsequent recognition test, and that participants evidenced superior recognition memory for the relatively easy to verbalize items. Baddeley (2007) showed that items richly encoded in meaning are those that are best recalled.

There is limited empirical evidence that the aphasia population presents with reduced ability to use covert verbal mediation. Goodglass, Denes, and Calderon (1974) found no evidence of verbal mediation in PWA in a visual STM task. PWA displayed equally diminished performances on a task matching objects with “acoustically” (Goodglass et al., 1974, p. 264) (i.e., phonologically) similar and dissimilar names, while brain-injured non-aphasic participants exhibited inferior performance matching phonologically similar names. These results were taken as evidence that phonologically similar names caused interference in covert verbal mediation in non-aphasic participants, while the lack of interference in PWA was viewed as evidence for an absence of covert verbal mediation in this group.

Theoretical framework

PWA are at a disadvantage in cognitive processes such as WM if they are unable to use covert verbal mediation. For the purposes of this study, I used Baddeley and Hitch's (1974) theoretical framework of WM. WM is unique from STM, in that this temporary storage of information is also processed and manipulated to accomplish a task; it takes into account storage capacity, attention, and executive processes. Goal-relevant information in WM is refreshed and maintained by a rehearsal process. Recycling information refreshes the memory trace; if the trace decays, information is lost. Baddeley proposed a multi-component system for temporarily storing and manipulating information. The central executive system (Baddeley, 1986) regulates the admission of information into WM and is responsible for attentional control processes. It contains two modality-specific components – the visuospatial sketchpad and the phonological loop. The visuospatial sketchpad is responsible for temporarily retaining visual and spatial information. For example, we may employ it when we give someone directions to our house. The phonological loop is responsible for the temporary rehearsal of verbal information.

The phonological loop is comprised of two subsystems (Baddeley and Hitch, 1974). The first subsystem is the phonological input store, which is responsible for retaining verbal information. Several studies describe phonological encoding and the effects of phonemic similarity on recall as evidence for the existence of a phonological loop. Phonologically similar consonants/ word lists are more prone to recall error than phonologically dissimilar consonants/ word lists (Baddeley, 1966; Conrad, 1964; Conrad & Hull, 1964), suggesting words are at least partially coded phonologically. Conrad and

Hull (1964) also demonstrated that STM span is dependant on phonological encoding and subvocal rehearsal of visually presented information. There are at least two sources of input to the phonological loop in common WM span tasks depending on the nature of the stimuli used. In direct auditory span tasks, the phonological input is provided by the examiner in the form of spoken words, digits, etc. In picture span tasks, participants internally generate phonological input based on lexical retrieval of the relevant word. The second subsystem is the articulatory rehearsal process. The number of elements that can be maintained in WM is thought to be a function of the rate at which elements dissolve in addition to the speed of rehearsal processes. Baddeley, Thomson, and Buchanan (1975) have demonstrated a word length effect in WM. They found that short, monosyllabic words were better retained than long, polysyllabic ones that require more time to articulate.

A third component of the central executive system is the episodic buffer, which serves as an interface between WM and long-term memory (Baddeley, 2000; Baddeley, 2007). The episodic buffer aids maintenance of information. WM is a capacity-limited system, and relevant information can be lost when the system is taxed beyond capacity, causing people difficulty completing tasks that rely on heavy active maintenance of relevant information.

WM and its relationship to language

Findings from both behavioral and neuroimaging studies of NI individuals provide reasons to expect that WM is related to language production and comprehension, and that verbal WM impairments may be related to language impairments associated with aphasia. Span measures in particular have been used to quantify verbal WM ability and have been assessed for construct validity and reliability (Waters & Caplan, 2003). Waters and Caplan (2003) calculated a composite score across three measures (subtract-2 span, alphabet span, and reading span), which is now considered a “gold standard” battery for verbal WM for NI individuals. Researchers have reported a relationship between WM and language comprehension (DeDe, Caplan, Kemtes, & Waters, 2004). DeDe, et al. (2004), showed that verbal WM capacity (as measured by the “gold standard” battery) is predictive of performance on measures of sentence- and paragraph-level comprehension in NI adults. Thus, verbal WM impairments could affect comprehension of spoken or written language. Neuroanatomical substrates of verbal WM overlap with regions of the brain that are often damaged in PWA. Smith and Jonides (1998) conducted neuroimaging studies that have shown Broca’s area is involved with subvocal rehearsal and the left posterior parietal cortex is involved in short-term storage of verbal information. Lesions in these areas are associated with aphasia and suggest that it is important to understand how verbal WM impairments contribute to communication disorders in PWA.

Indeed, recent research suggests that PWA often have WM impairments (Caspari, Parkinson, LaPointe, & Katz, 1998; Friedmann & Gvion, 2003; Mayer & Murray 2012), which contribute to language-processing difficulties. WM tasks designed for PWA include listening span, forward and backward versions of picture span, and n-back tasks. Caspari et al. (1998) determined that the ability of aphasic individuals to comprehend language is predictable from their WM capacities. They measured WM capacity using reading span and listening span, with sentence-final words that were high frequency, imageable, and monosyllabic. Instead of verbally recalling words, participants were required to recognize pictures among foils. There was a correlation between WM measures, measures of reading comprehension, and aphasia severity.

The n-back task as a measure of WM

N-back task performance has been used in recent studies as a measure of WM in PWA and NI individuals. Kirchner (1958) developed the n-back task to directly measure short-term retention. The task requires participants to indicate whether the present stimulus in a sequence matches one that appeared *n* items before by pressing a button to indicate a target. *N* is pre-specified and usually set to 0, 1, 2, or 3. Jonides et al. (1997) proposed seven processes required for successful n-back performance: encoding, storing, rehearsing, matching, ordering, inhibiting information, and executing a response. Because it requires the temporary storage and manipulation of information to achieve a cognitive goal, the n-back task parallels the definition of WM and is considered to have strong face validity. However, Jaeggi, Buschkuehl, Perrig, and Meier (2010) call into question the n-back's construct validity, due to mixed results when comparing it to complex span tasks to assess concurrent validity. These researchers hypothesized that successful n-back performance requires processes beyond traditional WM-related processes. For example, interference resolution may be needed to resolve conflicts when the current stimulus matches a previous stimulus, but not the one *n* back. Alternatively, because n-back demands speeded recognition as opposed to serial recall, the n-back and complex span tasks may measure different aspects of the same construct or possibly even different constructs. Nevertheless, the n-back paradigm is particularly well suited to measuring WM in PWAs because instructions are simple, it requires a recognition response (not a recall/ verbal response), data collection is automated, and stimulus type can be easily varied.

The n-back task and manipulation of linguistic load

Christensen and Wright (2010) manipulated the linguistic load of stimuli in the n-back task to examine the role language plays in WM. They found that PWA were less accurate on the n-back task overall compared to NI individuals, suggesting that their poorer performance was not only due to language impairment, but also to concomitant cognitive deficits. In addition, these researchers observed that PWA and NI individuals have increased accuracy when linguistic load is high in a 2-back condition. PWA performed better on linguistic stimuli (fruits) than semi-linguistic stimuli (“fribbles”) or non-linguistic stimuli (blocks). These results suggest that PWA were able to use linguistic strategies to facilitate performance, and that WM is substantially enhanced by verbal encoding. In the same 2-back condition, NI individuals performed better on fruits than fribbles and better on fribbles than blocks. In the 1-back condition, results indicated no significant differences for PWA. NI individuals had significant differences between fruits and fribbles, but no significant differences between fruits and blocks or fribbles and blocks. The researchers suggest this was likely the result of limited within-group variability for these stimuli and not meaningful given their high performance on all 1-back tasks.

Mayer and Murray (2012) investigated the effect of high frequency words, low frequency words and “non-nameable” stimuli (faces) on n-back task performance. They found that PWA performed better on nameable (high and low frequency words) compared to non-nameable (faces) stimuli with a significant decrement for low frequency words only in the 2-back condition. Interestingly, there was a significant difference on visual confrontation naming (VCN) of high vs. low frequency words, but no difference in n-back task performance in most conditions. The researchers suggest one possible explanation for their negative result regarding an n-back word frequency effect is that the n-back task requires only “conceptual and/ or lemma level retrieval” (p. 336), whereas the VCN task requires retrieval of the phonological word form, as well as conceptual and/ or lemma retrieval. For both PWA and NI populations, responses in 2-back conditions were significantly less accurate and marked by increased latency (Christensen & Wright, 2010; Mayer & Murray, 2012).

Articulatory suppression

Articulatory suppression conditions provide evidence for the disruption of successful covert verbal mediation in short-term recall tasks. The basis of this phonological loop disruption lies in articulatory suppression preventing retrieval/ rehearsal of verbal information by having participants repeat an irrelevant word during stimulus input. For example, Baddeley, Lewis, and Vallar (1984) revealed that for NI participants, articulatory suppression reduced memory span for visually presented digits, and Russo and Grammatopoulou (2003) revealed that articulatory suppression eliminated the classical word length effect (lists of short words are recalled better than lists of long words), particularly in short-term recall tasks. However, evidence of this disruption has not been found in n-back tasks. In an unpublished study (Pitman & Ruscin, 2009) of NI participants, researchers found no significant main effect of experimental condition (baseline vs. articulatory suppression). Instead, accuracy was greater for whichever condition participants completed first. The researchers hypothesized that either accuracy was not detrimentally affected by articulatory suppression because the phonological loop is not used during the n-back task, or that the phonological loop was used but was not impaired by the articulatory suppression condition. There is no known research to date that explores the effect of articulatory suppression on n-back task performance in PWA.

Research question

Results of the previously reviewed studies indicate language deficits and concomitant WM deficits in PWA; however, further research is needed to describe the relationship between language processing/ performance and WM. Wright and Fergadiotis (2012) state that most studies investigating the relationship between language processing and WM abilities in aphasia have focused on comprehension ability only. By further investigating the relationship between production ability (overt naming performance) and WM, I sought to determine if PWA use intact word retrieval to facilitate performance on the n-back task. Additionally, I used an articulatory suppression condition to determine if disruption of the phonological loop impaired the use of verbal mediation to support WM.

The present study

The present study explored the relationship between lexical access and n-back task performance in PWA and NI individuals. Lexical access was measured by VCN task performance, and unique sets of stimuli were developed for each participant based on the accuracy, consistency, and latency of responses. The n-back task was manipulated with regard to load (n=0, 1, 2), stimulus type (“readily nameable”/ high frequency objects, “unnameable”/ low frequency objects, blocks), and access to the phonological loop (baseline and articulatory suppression conditions).

Based on previous n-back studies, I hypothesized that NI participants would perform with greater accuracy than PWA across all conditions and that both groups of participants would exhibit decreased n-back performance with increased processing load. I made the following specific predictions with regard to PWA and NI ability to complete the n-back task based on overt naming ability and disruption of the phonological loop:

1. PWA will perform with greater accuracy with readily nameable stimuli than with unnameable stimuli or block stimuli under the baseline condition.
    a. This result would suggest that PWA use intact lexical retrieval to facilitate n-back performance.
    b. When PWA are able to retrieve specific lexical items, they employ verbal mediation as a strategy to facilitate n-back performance.
2. For readily nameable stimuli, PWA will perform with greater accuracy under the baseline condition than under the articulatory suppression condition.
    a. This result would suggest that PWA's preserved lexical retrieval, that can be used to facilitate n-back performance under a baseline condition, is degraded in a condition that disrupts their use of the WM phonological loop.
    b. When PWA are able to retrieve specific lexical items, n-back performance is facilitated by verbal mediation; however, when use of the WM phonological loop is disrupted by articulatory suppression, retrieved phonological word forms cannot be used to support n-back performance.
3. For unnameable stimuli and block stimuli, PWA will perform with equal accuracy under the baseline and articulatory suppression conditions.

    a. This result would suggest that when PWA are unable to retrieve specific phonological word forms, they are not able to employ the WM phonological loop to support n-back performance.
    b. When PWA are unable to retrieve specific lexical items, n-back performance is not facilitated by verbal mediation and they do not have available a language strategy to complete the task.

4. NI will perform with greater accuracy with high and low frequency stimuli than with block stimuli under the baseline condition.
    a. This result would suggest that when lexical representations are available for specific items, NI use their intact lexical access to facilitate n-back performance.
    b. When NI are able to retrieve specific lexical items, n-back performance is facilitated by verbal mediation and they use a language strategy to complete the task.
5. For high and low frequency stimuli, NI will perform with greater accuracy under the baseline condition than under the articulatory suppression condition. Performance on the block stimuli will be the same under the baseline and articulatory suppression conditions.
    a. This result would suggest that under the articulatory suppression condition, NI experience a disruption of the WM phonological loop, thereby decreasing their ability to employ their intact lexical access to facilitate n-back performance.

Chapter 2: Methods

Participants

Four PWA (PWA1-PWA4) and four age- and education-matched NI (NI1-NI4) individuals participated in this study on a volunteer basis. Inclusion criteria for the PWA participants included (a) medical diagnosis of a single unilateral left-hemisphere stroke, (b) at least three months time post-onset (TPO), and (c) presence of aphasia as indicated by a *Western Aphasia Battery-Revised* Aphasia Quotient (WAB-R AQ) (WAB-R; Kertesz, 2006) of less than 93.8 obtained within the past three months. Two PWA participants had a concomitant apraxia of speech diagnosis. Criteria for all participants included (a) native English-speaking monolingual, (b) pre-morbid right handedness, (c) sufficient dexterity control in the left hand to push a laptop computer spacebar, (d) aided or unaided vision within normal limits as indicated by a simple picture-matching screening measure (Gellert, unpublished), (e) aided or unaided hearing within normal limits as indicated by self-report, (f) no history of other neurological impairment as indicated by self-report, (g) score within normal limits on the *Mini Mental State Examination* (MMSE; Folstein, Folstein, & McHugh, 1975), and (h) meeting performance requirements on a visual confrontation naming (VCN) task (see below: *Stimuli for the experimental n-back tasks*). Demographic information for both the PWA and NI participants is displayed in Table 1. Wilcoxon signed rank tests revealed no significant difference between the PWA and NI groups for either age or education.

Table 1: Demographic information

Participant	**Age**	**Gender**	**Level of Education**	**TPO (months)**	**WAB-R AQ**	**WAB-R Profile**	**WAB-R Object Naming**	**VCN Naming Score**	**Apraxia Diagnosis**
PWA1	84	M	16+	36	69.0	Anomic	42	47%	No
PWA2	55	F	16	84	67.0	Conduction	52	69%	Yes
PWA3	55	M	12+	48	87.2	Anomic	51	64%	No
PWA4	52	M	16+	120	72.3	Broca's	58	56%	Yes
NI1	61	F	16+						
NI2	61	F	16						
NI3	64	M	16+						
NI4	70	M	16+						
PWA Group	M= 61.50 SD= 15.07	Male= 3 Female= 1	M=15.00 SD=2.00	M= 72.00 SD= 37.95	M= 73.90 SD= 9.10		M= 50.75 SD= 6.60	M= 26.5 SD= 4.43	
NI Group	M= 64.00 SD= 4.20	Male= 2 Female= 2	M=16.00 SD=0.00						

Note. The VCN Naming Score is the percent of accurate and timely responses from the first trial of the VCN task (x/45).

Participants were recruited at a Washington, DC metropolitan area facility, and were selected to participate in the study based on the previously stated parameters. Consent forms and assessment of participants (background questions, vision screen, WAB-R, MMSE, VCN task) were completed during an initial assessment session. Experimental sessions (n-back tasks) took place within 3 weeks of assessment sessions, depending on participant availability. This study was approved by the Institutional Review Board at The George Washington University.

Stimuli and procedures for the VCN task

A VCN task was programmed using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) and administered on a laptop computer. The stimuli for this task were 45 pictures selected from colored Snodgrass & Vanderwart ‘Like’ Objects (Rossion & Pourtois, 2004); pictures selected included only 1-2 syllable inanimate objects. Normative data similar to the original black and white Snodgrass and Vanderwart Objects (1980) have been collected. Pictures were retrieved from: http://wiki.cnbc.cmu.edu/Objects.

Each stimulus picture was displayed on the computer screen for 800 ms (exposure time). An inter stimulus interval (ISI) of 1600 ms separated the pictures. The durations of the exposure time (ET) and ISI were set to match the parameters of the experimental n-back task used in this study. During the VCN task, a verbal response was required from the PWA, and only brief, supportive feedback (i.e., “that’s okay,” “keep going”) was provided to ensure continued responsiveness. No cues to facilitate naming were provided by the investigator. Two trials of the entire pool of 45 objects were administered. A third, untimed trial (<10 seconds per object) was administered for objects that were readily named twice or unnamed twice in the initial two trials to ensure their appropriateness for stimulus selection.

Stimuli for the experimental n-back tasks

Two sets of linguistic stimuli were selected for each participant in this study. For PWA participants, the two sets of linguistic stimuli were determined by their performances on the VCN task. Determination of "readily nameable" and "unnameable" stimuli was based on response accuracy, 100% consistency of response type across all three trials, and latency (less than 2400 ms [ET+ISI]). To determine accuracy, responses that contained a phonetic distortion, but were otherwise recognizable as the target word, were accepted as nameable. Objects that evoked neologisms, semantic paraphasias, semantically unrelated words, circumlocutions, and "I don't know" responses were treated as unnameable. Objects that evoked other response types, including mixed phonemic-semantic paraphasias, self-corrections, and 2+ word responses were removed from the stimulus pool. Eight stimuli (Christensen & Wright, 2010) were identified for each linguistic set. "Readily nameable" stimuli were named correctly on all three trials; "unnameable" stimuli were failed on all three trials. If a PWA participant achieved more than eight stimuli in either readily nameable or unnameable sets, the eight highest and eight lowest in word frequency counts were chosen, respectively, for use in the n-back task. Written word frequency counts were determined according to Kucera and Francis (1967) data.

A practice VCN task with five separate objects was conducted to acclimate participants to the rapidity with which the pictures were presented and the type of response required. All naming responses were recorded and subsequently orthographically transcribed independently by the investigator and by a second-year graduate student in speech-language pathology familiar with the verbal output of PWA. Transcriptions were assigned to readily nameable, unnameable, or “remove from stimulus pool" categories based on the above criteria. Only transcriptions that were placed by both examiners into the same category were included in the stimulus sets. The unique linguistic stimulus sets selected for PWA participants are included as Appendix A.

NI participants also completed the VCN task. Because NI participants were expected to accurately name all objects, their two sets of linguistic stimuli were determined by word frequency counts. For each participant, “high frequency” stimuli were the eight most frequent objects named accurately, and “low frequency stimuli” were the eight least frequent objects named accurately. Similar to the PWA group, items that evoked self-corrections and 2+ word responses were removed from the stimulus pool; requirements for consistency and latency were the same as the PWA group. The unique linguistic stimulus sets selected for NI participants are included in Appendix A.

A third set of stimuli served as non-linguistic stimuli (Christensen & Wright, 2010) for all participants. These stimuli were pictures of block designs; i.e., three-dimensional blue-color cubes connected in different arrays. Stimuli were gathered from Shepard and Metzler’s (1971) study on mental rotation tasks; none of the block designs selected for use in this experiment was a rotation of another block design. Pictures were retrieved from: http://librebraintraining.org/development/Shepard-Metzler-item-set/.

Procedures for the experimental n-back tasks

The n-back tasks were programmed using E-Prime and administered on a laptop computer. The ET for the stimuli was set at 800 ms and the ISI was set at 1600 ms

(Mayer & Murray, 2012). This presentation rate was selected to discourage attempts to covertly verbalize unnameable and block stimuli. For experimental tasks, targets were presented at a rate of 31% (15 targets from 48 items), consistent with previous research (Christensen & Wright, 2010; Mayer & Murray, 2012). The maximum number of sequential hits in all tasks was limited to three. Stimuli for experimental tasks were unique to each participant and based on VCN task performance; pictures were the same as those used in the VCN task.

All participants performed 18 n-back tasks that were fully crossed in terms of load (n=0, 1, 2), stimulus type (readily nameable/ high frequency, unnameable/ low frequency, blocks) and baseline/ articulatory suppression conditions. All participants completed six 0-back tasks followed by six 1-back tasks followed by six 2-back tasks. At each load level, three tasks were completed under a baseline condition and three tasks were completed under articulatory suppression; the presentation order for these conditions was counterbalanced across participants and remained fixed for each participant at all load levels. At each load level under each condition, blocks were presented first because participants were expected to have the least accurate and most latent responses for non-linguistic stimuli. Presentation order for the two sets of linguistic stimuli was counterbalanced across participants and remained fixed for each participant at all load levels/ conditions. A list of experimental tasks and the order of administration for each participant is included as Appendix B.

Participants were instructed to respond by pushing the laptop computer spacebar with their left hand, and to do so as accurately and quickly as possible before the next picture appeared. All participants used their left hand because some PWA participants were unable to respond with their right hand due to hemiparesis. For the 0-back task, a response was required when a pre-specified picture (i.e., book) was presented. For the 1-back and 2-back tasks, a response was required when the picture participants just saw was the same as the one *n* back (n=1, 2). Participants were instructed to remain silent while completing the n-back tasks under the baseline condition. Participants were instructed to say “Monday” aloud, and in time with a metronome while completing the n-back tasks under the articulatory suppression condition. Rate of production of “Monday” was set at 800 ms and synchronized with picture onset. An optional rest break was offered after each task was completed.

Before beginning each load level, a practice task with verbal instruction and paper illustrations was given and repeated until participants demonstrated understanding of the task by pointing to targets with 100% accuracy. Participants were then given the option to complete the practice task on the laptop computer under both baseline and articulatory suppression conditions. All PWA participants and three out of four NI participants completed a practice session prior to the 0-back task under the baseline condition. Practice tasks consisted of ten items with three targets (30% hit rate). Stimuli for these tasks were the three highest frequency objects from each participant’s readily nameable/ high frequency linguistic set.

Accuracy and reaction time were collected in E-Prime for each participant response. Accuracy is reported as an A-prime (A’) score for each task. A’ is a type of d’ statistic that is appropriate for nonparametric data and controls for response bias. Responses were categorized as hits and false alarms. Hit rates (H) and false alarm rates (FA) were the probability that an item would cross a recognition threshold and were calculated as: $H = x/15$ (actual true positives/possible true positives), and $FA = y/33$ (total false positives/possible true negatives). Because the probabilities of hit rate and miss rate summed to 1.0, as did the probabilities of false alarms and correct rejections, H and FA accounted for hits, misses, false alarms, and correct rejections. H and FA were used to calculate A’ ($A'=1/2+[(H-FA)(1+H-FA)]/[4H(1-FA)]$) (Donaldson, 1992). Appendix C includes raw data for hits and false alarms. Reaction times were manually collected for hits only, and a mean reaction time (RT) for each task was calculated in milliseconds. Mean RT for false alarms were collected as a separate measure for data analysis. If in either instance a participant responded twice to one stimulus, the RT from the first response was used. Response times were not analyzed as part of the present study. Appendix D provides the mean RTs for hits only. Appendix E provides the mean RTs for false alarms only.

A brief post-experiment interview was conducted with each of the participants. Open-ended questions (Appendix F) were asked to understand what strategies participants purposefully adopted to complete the tasks. Interviews were audio recorded.

Data analysis (A’)

A series of permutations tests was performed to compare the performance of the PWA and NI groups for each of the 18 experimental tasks; the permutation test is appropriate for use with nonparametric data (Good, 2010). A test statistic (sum of observed data with PWA label) was computed for the original observations. Next, the observed data were rearranged and a test statistic (sum of permuted data with PWA label) was computed for each of the new arrangements. The values for the observed test statistic were compared with those of the permuted test statistics. The null hypothesis was rejected at the .05 level, i.e., from 70 permutations, the test statistic for the observed data needed to fall among the four highest or four lowest sums to be considered significant. When the value of the test statistic as it was originally labeled is an extreme value, there is a <6% probability that it falls within the region of rejection by chance.

A series of Friedman's Two-Way Analysis of Variance by Ranks tests (Siegel & Castellan, 1988) for nonparametric data was performed to examine differences among the three levels of load and among the three stimulus types for both the PWA and NI participants under both the baseline and articulatory suppression conditions. A significance level of .05 was used for all of these tests. Friedman's test for multiple comparisons was applied in all cases where a significant difference was found among the load levels or stimulus types to identify which pairs were significantly different from one another. Note that a Bonferroni correction was not employed for these analyses.

A series of Wilcoxon signed-rank tests (Siegel & Castellan, 1988) for nonparametric data was performed to examine for differences between the two conditions (baseline and articulatory suppression) for both the PWA and NI participants. A significance level of .05 was used for all of these tests. Note that a Bonferroni correction was not employed for these analyses.

A series of Crawford's *t*-test was performed to compare individual PWA scores against norms derived from the NI sample (N=4) for each of the 18 experimental tasks. Crawford and Howell (1998) developed this modified *t*-test to compare an individual's test score with a normative sample when the normative sample is small (N<50); it is appropriate for use with nonparametric data. A significance level of .05 was used for all of these tests. A one-tailed *t*-test was performed because it was predicted *a priori* that the

PWA participants' scores would fall below those of the NI participants. Note that a Bonferroni correction was not employed for these analyses. A program used to obtain results was retrieved from: http://homepages.abdn.ac.uk/j.crawford/pages/dept/psychom.htm.

Chapter 3: Results

VCN task results

Responses to the VCN task (see Appendix A) reveal that there was a frequency effect distinguishing the linguistic sets for the PWA participants, with one exception – PWA1 had one object in his readily nameable set which had a frequency count equal to the lowest frequency word in his unnameable set. Baring this single exception, readily nameable objects were high frequency words and unnameable objects were low frequency words. There was a greater frequency distribution in both sets for PWA participants than for NI participants. The mean Kucera-Francis Frequency Count for the PWA group was 121.25 for readily nameable objects and 38.16 for unnameable objects. The mean for the NI group was 138.03 for high frequency objects and 29.38 for low frequency objects.

Experimental n-back task results (A')

Individual A' scores and mean A' for the PWA and NI participants for each task are shown in Table 2.

Table 2: A' scores for each subject for each load and stimulus combination under baseline and articulatory suppression conditions

	n=0			**n=1**			**n=2**		
	Readily Nameable/ High Frequency	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**
Baseline									
PWA1	.93	1.0	.95	.93	.52	.77	.87	.80	.74
PWA2	1.0	1.0	.95	.85	.92	.92	.85	.81	.68
PWA3	1.0	.97	.97	.95	.95	.94	.70	.87	.39
PWA4	1.0	1.0	1.0	.97	.92	.92	.83	.87	.61
	M=.98 SD=.04	M=.99 SD=.02	M=.97 SD=.02	M=.93 SD=.05	M=.83 SD=.21	M=.89 SD=.08	M=.81 SD=.08	M=.84 SD=.94	M=.61 SD=.15
NI1	1.0	1.0	.98	.98	.97	.97	.97	.90	.85
NI2	.91	1.0	.98	.98	1.0	.99	.93	1.0	.91
NI3	1.0	1.0	.98	.97	1.0	.97	.77	.97	.83
NI4	.98	1.0	1.0	1.0	1.0	1.0	.44	.90	.76
	M=.97 SD=.04	M=1.0 SD=0	M=.99 SD=.01	M=.98 SD=.01	M=.99 SD=.02	M=.98 SD=.02	M=.78 SD=.24	M=.94 SD=.05	M=.84 SD=.06

	n=0			**n=1**			**n=2**		
	Readily Nameable/ High Frequency	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**
Articulatory Suppression									
PWA1	1.0	1.0	.93	.98	1.0	.97	.85	.72	.69
PWA2	.98	1.0	.97	.91	.90	.89	.85	.78	.63
PWA3	1.0	1.0	.94	.95	.90	.94	.57	.89	.84
PWA4	1.0	.99	.87	.87	.93	.92	.83	.83	.76
	M=1.0 SD=.01	M=1.0 SD=.01	M=.93 SD=.04	M=.93 SD=.05	M=.93 SD=.05	M=.93 SD=.03	M=.78 SD=.14	M=.81 SD=.07	M=.73 SD=.09
NI1	1.0	1.0	.99	1.0	.98	.99	1.0	.81	.80
NI2	1.0	1.0	.90	.98	.97	.99	.98	.99	.90
NI3	1.0	1.0	.98	.93	.98	.97	.64	.90	.66
NI4	1.0	.99	.96	.97	.97	.95	.30	.87	.52
	M=1.0 SD=0	M=1.0 SD=.01	M=.96 SD=.04	M=.97 SD=.03	M=.98 SD=.01	M=.98 SD=.02	M=.73 SD=.33.	M=.89 SD=.08	M=.72 SD=.17

Comparisons between PWA and NI participants' performances

Mean A' for the PWA and NI participants in each combination of stimulus type and n-back load under the baseline condition is shown in Figure 1. The PWA's and NI's A' scores were compared using permutation tests. These comparisons revealed five differences which fell within the region of rejection (<6% by chance) under the baseline condition. The five significant differences were found at n=1 readily nameable/ high frequency, n=1 unnameable/ low frequency, n=1 blocks, n=2 unnamable/ low frequency, n=2 blocks. In all five significant differences, NI participants performed with greater accuracy than did the PWA participants.

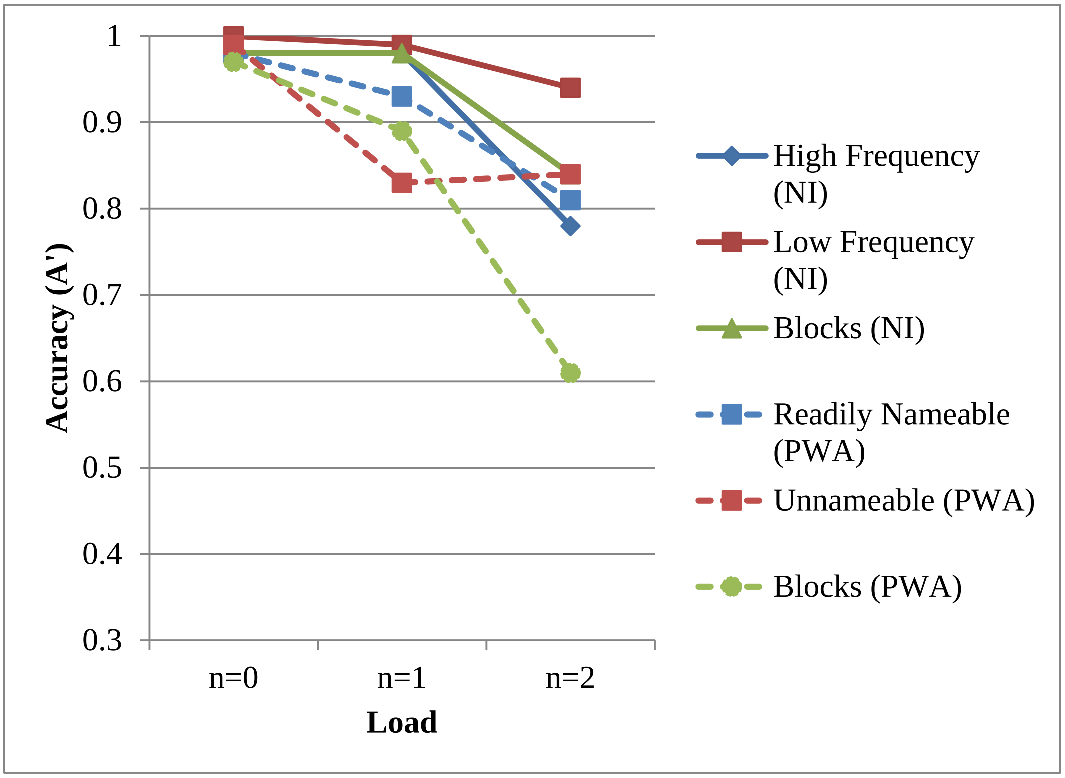

Figure 1. Mean A' comparisons between PWA participants and NI participants under the baseline condition.

Mean A’ for the PWA and NI participants in each combination of stimulus type and n-back load under the articulatory suppression condition is shown in Figure 2. The PWA’s and NI’s A’ scores were again compared using permutation tests. Observed differences which fell within the region of rejection (<6% by chance) under the articulatory suppression condition were as follows: n=0 blocks, n=1 readily nameable/ high frequency, n=1 unnameable/ low frequency, n=1 blocks. Here again, for all significant differences, NI participants performed with greater accuracy than did the PWA participants. Results of the permutation tests are provided as Appendix G.

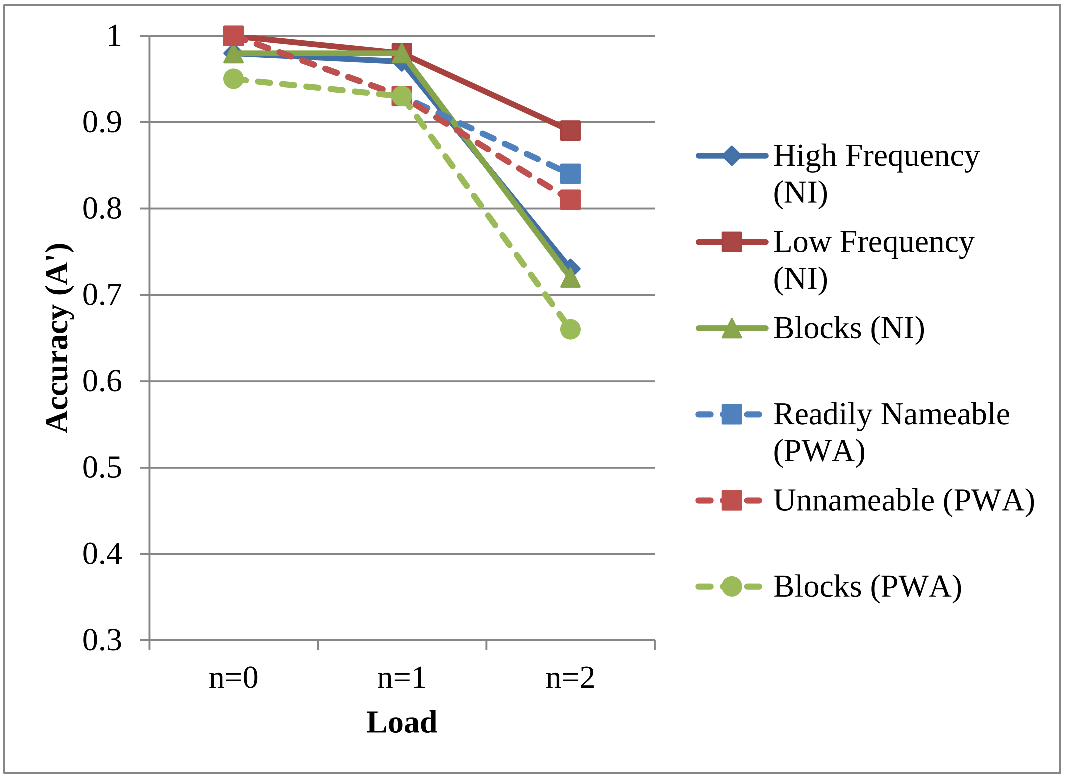

Figure 2. Mean A’ comparisons between PWA participants and NI participants under the articulatory suppression condition.

Comparisons among load levels

Mean A’ for PWA participants in each load level for each stimulus type under the baseline condition is shown in Figure 3. Results under the articulatory suppression condition are shown in Figure 4.

Comparisons among the load levels using Friedman’s Two-Way Analysis of Varience by Ranks revealed five significant differences. For the PWA participants, two significant differences were found under the baseline condition and three significant differences were found under the articulatory suppression condition. Under the baseline condition, a significant difference was found for PWA for the unnameable stimuli (Fr = 6.50, n=4, k=3) and block stimuli (Fr = 8.00, n=4, k=3). For PWA participants under the articulatory suppression condition, a significant difference was found for the readily nameable stimuli (Fr = 8.00, n=4, k=3) and unnameable stimuli (Fr = 7.13, n=4, k=3). No significant differences were found for NI participants under the baseline condition. For NI participants under the articulatory suppression condition, a significant difference was found for the low frequency stimuli (Fr = 6.50, n=4, k=3). A table of results is provided as Appendix H.

In all five instances where a significant difference was found among the load levels, the significant difference was between n=0 and n=2, with greater accuracy at the n=0 processing load. No other pair-wise comparisons among the load levels reached significance. A table of results is provided as Appendix I.

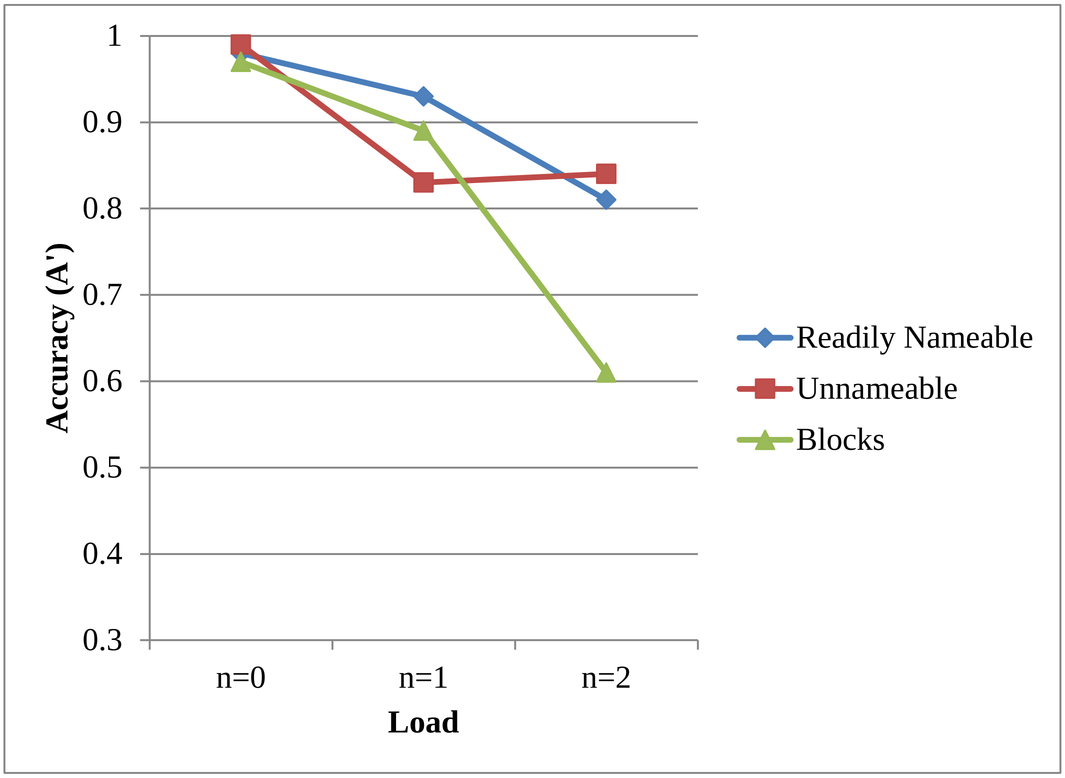

Figure 3. Mean A' comparisons for PWA participants under the baseline condition.

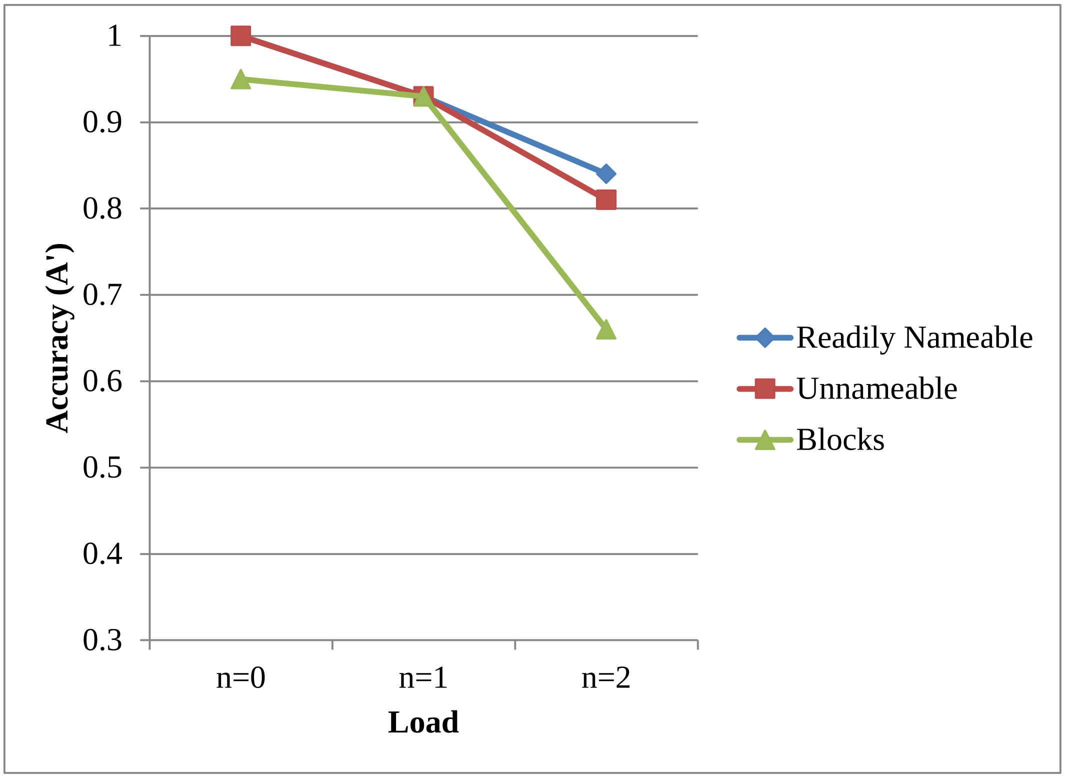

Figure 4. Mean A' comparisons for PWA participants under the articulatory suppression condition.

Comparisons among stimulus types

Comparisons among the three stimulus types for PWA and NI participants at each load level under both the baseline and articulatory suppression conditions were conducted using Friedman's Two-Way Analysis of Variance by Ranks. None of the comparisons among the stimulus types was significant for the PWA or the NI participants under either condition.

Comparison between baseline and articulatory suppression conditions

PWA and NI performances under the baseline and articulatory suppression conditions were compared for each stimulus type at each load level using Wilcoxon signed-rank tests. None of the comparisons between the conditions was significant for the PWA or the NI participants.

Comparison of individual PWA performances versus mean performances by NI participants

Comparisons between individual PWA A's and the mean A' for the NI participants were conducted using Crawford's *t*-test. These 72 tests yielded 23 significant differences. For the PWA participants, 15 significant differences were found under the baseline condition and eight significant differences were found under the articulatory suppression condition. For all significant differences, PWA participants performed with decreased accuracy when compared to the NI average. A table of results is included as Appendix J.

PWA1 differed significantly from the NI average for the following tasks under the baseline condition: n=0 blocks (t= -3.58), n=1 readily nameable (t= -4.47), n=1 unnameable (t= -21.02), n=1 blocks (t= -9.39), n=2 unnameable (t= -2.50). No other task yielded significant findings under the baseline condition. No task yielded significant differences under the articulatory suppression condition.

PWA2 differed significantly from the NI average for the following tasks under the baseline condition: n=0 blocks (t= -3.58), n=1 readily nameable (t= -11.63), n=1 unnameable (t= -3.13), n=1 blocks (t= -2.68). No other task yielded significant findings under the baseline condition. PWA2 differed significantly from the NI average for the following tasks under the articulatory suppression condition: n=0 readily nameable (t= -17.89), n=1 unnameable (t= -7.16), n=1 blocks (t= -4.03). No other task yielded significant findings under the articulatory suppression condition.

PWA3 differed significantly from the NI average for the following tasks under the baseline condition: n=0 unnameable (t= -26.83), n=1 readily nameable (t= -2.68), n=2 blocks (t= -6.71). No other task yielded significant findings under the baseline condition. PWA3 differed significantly from the NI average for the following tasks under the articulatory suppression condition: n=1 unnameable (t= -7.16). No other task yielded significant findings under the articulatory suppression condition.

PWA4 differed significantly from the NI average for the following tasks under the baseline condition: n=1 unnameable (t= -3.13), n=1 blocks (t= -2.68), n=2 blocks (t= -3.43). No other task yielded significant findings under the baseline condition. PWA4 differed significantly from the NI average for the following tasks under the articulatory suppression condition: n=0 unnameable (t= -8.94), n=1 readily nameable (t= -2.98), n=1 unnameable (t= -4.47), n=1 blocks (t= -2.68). No other task yielded significant findings under the articulatory suppression condition.

Figures 5 and 6 display representative data for individual PWA versus mean NI scores. Figure 5 displays the relationships between individual PWA scores to the mean NI score for the block stimulus type under the baseline condition. Figure 6 compares individual PWA scores to the mean NI score for the n=2 load level under the baseline condition. Figures for all comparisons and conditions are included as Appendix K.

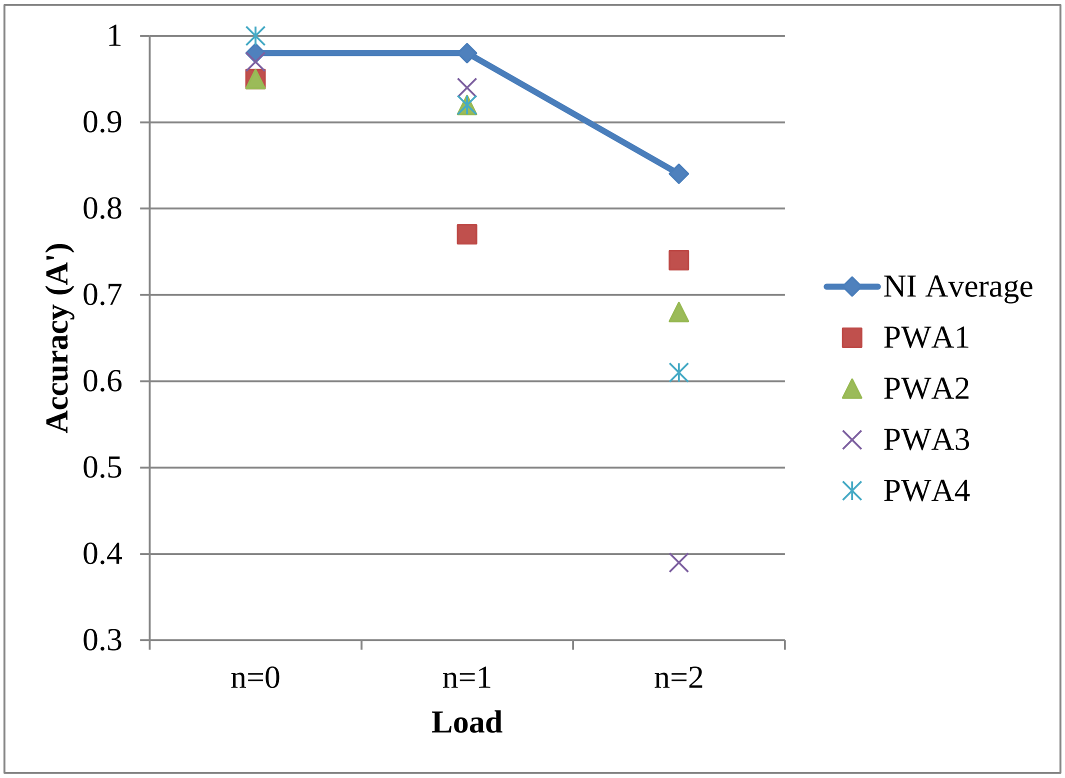

Figure 5. Individual A' scores for PWA participants compared to the mean A' for NI participants for the block stimulus type under the baseline condition.

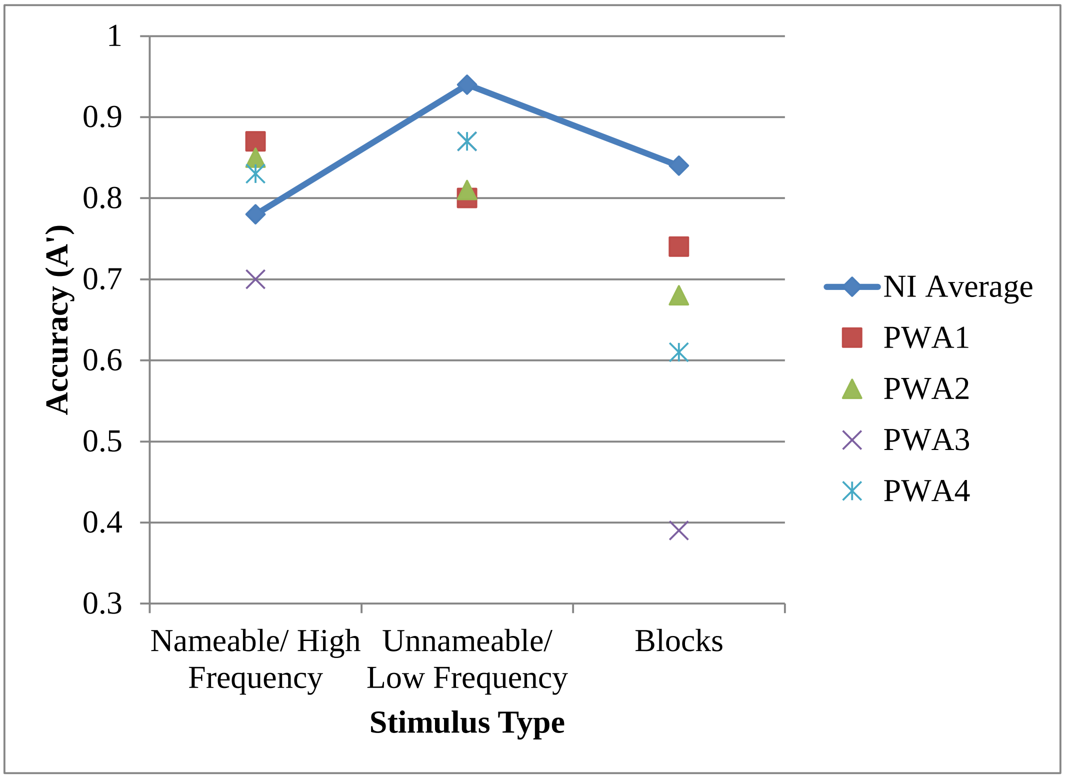

Figure 6. Individual A' scores for PWA participants compared to the mean A' for NI participants for n=2 load level under the baseline condition.

Post-experiment interview results

The post-experiment interviews reveal that all participants found the 2-back tasks, block tasks, and articulatory suppression condition to be the most difficult. Three out of four PWA participants reported trying to name the objects, two tried to name the blocks. Two PWA participants reported continued attempts to name the objects under the articulatory suppression condition. Two out of four NI participants reported trying to name the objects, one tried to name the blocks. These two NI participants reported continued attempts to name the objects under the articulatory suppression condition.

Paraphrased responses for each participant are included as Appendix L.

Chapter 4: Discussion

In this study I investigated the relationship between lexical access and performance on a working memory task (n-back) to determine if PWA use intact word retrieval (verbal mediation) to support working memory. An articulatory suppression condition was also conducted to determine if disruption of the working memory phonological loop impairs the use of verbal mediation. In the following sections I examine the results for each of the research questions posed above; results only partially supported my predictions. The small sample size precludes my drawing strong conclusions – results may reflect outliers and not PWA or NI groups as a whole. Therefore, generalizing the findings are cautioned. Additionally, because a Bonferroni correction was not applied during data analysis, results should be interpreted with caution. Nonetheless, trends and emerging patterns are useful for tailoring future research and clinical assessment.

Aphasia and concomitant WM deficits

Comparisons of PWA n-back performances with NI performances partially supported the existence of concomitant WM deficits in PWA. At the 0-back level, both PWA and NI participants performed with high accuracy. At the 1-back level, significant results were obtained in the direction of PWA < NI. While the NI participants maintained their high accuracy at this load level, PWA participants performed with decreased accuracy. At the 2-back level, both PWA and NI participants performed with decreased accuracy. These results suggest that PWA's WM performance is more sensitive to changes in processing load – they demonstrated degraded performance when compared to the NIs at the 1-back level. Results from the Crawford's *t*-tests comparing individual PWA performances with mean NI scores corroborate this finding: 15 of the 23 significant findings occurred at the 1-back level in the direction of PWA participants performing at a level significantly below the NI average.

Processing load

Comparisons among processing load levels yielded five significant findings, four of which were for the PWA participants. In all instances, the significant difference was in the direction of n=0 > n=2. These results are consistent with previous literature (Christensen & Wright, 2010; Pitman & Ruscin, 2009) and support findings that increased processing load in an n-back task requires more cognitive resources regardless of brain damage. For example, of the processes identified by Jonides et al. (1997), ordering may be a cognitive process required at the 2-back level, but not the 0-back level. Finding only one significant difference for processing load for the NI participants (low frequency stimuli under articulatory suppression) was surprising. Previous research had shown a degradation of NI performance at n=2. Both Christensen and Wright (2010) and Mayer and Murray (2012) observed significant interactions between processing load and stimulus type and indicated that these interactions complicated interpretation of the processing load differences. It seems possible, in view of the overall performances of the NI participants, that the n-back tasks using visually distinct stimuli were not sufficiently taxing to reveal a traditional working memory load effect.

Lexical access (stimulus type)

I had hypothesized that PWA and NI participants would use intact lexical retrieval (readily nameable/ high and low frequency stimuli) to facilitate n-back performance. No significant results were obtained for either group of participants under the baseline condition when comparing stimulus types. The ability of participants to overtly name linguistic stimuli appears to be unassociated with their ability to use those stimuli covertly during the n-back task. An overarching explanation for this lack of findings is that because the n-back task is thought to minimize language demands, it is possible that WM function as measured by this task may not be measurable in terms of overt naming ability. If, however, the n-back task does allow true testing of lexical retrieval, two alternate explanations for the lack of significant findings are offered below.

First, it is possible that different task demands allow words to be retrieved under VCN conditions but not under n-back conditions. Mayer and Murray (2012) proposed that timing and linguistic resource availability may yield discrepant performances on VCN and n-back tasks when comparing high and low frequency words. They hypothesized that due to the time-limited nature of lexical retrieval in connectionist models (i.e., spreading activation), n-back time restrictions did not allow for activation to spread from the conceptual pre-lexical level to phonological levels in time for an observable word frequency effect. In the present study, however, VCN and n-back tasks were both completed within identical time limits, rendering the above explanation unsatisfactory. Mayer and Murray alternatively hypothesized that the n-back task taxes linguistic processing at the conceptual pre-lexical level. If this is true, overt performance – which requires retrieval of phonological word forms – would not reflect n-back performance. Under n-back conditions, word retrieval would be confounded by the cognitive resource demands of the n-back task. The additional resources required to retrieve words at the phonological level would be usurped by the working memory effort required to execute the n-back task.

The second explanation is that participants used the visuospatial sketchpad to complete the n-back task. It is possible that participants relied solely on the use of the visuospatial sketchpad regardless of stimulus type, or they were able to use it in addition to intact lexical retrieval or when lexical retrieval failed. Use of the visuospatial sketchpad may have been facilitated by the use of highly distinct colored pictures for the linguistic stimuli. The non-linguistic block stimuli would require use of the visuospatial sketchpad in any case. Anecdotal evidence from the post-experiment interviews indicated that six participants tried to use a naming strategy, and one reverted to a visual strategy when the naming strategy failed. Results are inconclusive as to whether intact lexical access facilitated n-back performance, and thus whether verbal mediation was employed as a strategy.

Disruption of the WM phonological loop (articulatory suppression)

I had predicted that PWA would perform with greater accuracy for readily nameable stimuli under the baseline condition, and that NI would perform with greater accuracy for both high and low frequency stimuli under the baseline condition than under the articulatory suppression condition. Such findings would have indicated that preserved retrieval of phonological word forms could be used to facilitate WM performance. No significant results were obtained when comparing baseline and articulatory suppression conditions for either group of participants. Results indicated that NI's lexical retrieval and PWA's preserved lexical retrieval were not degraded in the articulatory suppression condition; i.e., one that was expected to disrupt their use of the WM phonological loop. It is possible that retrieved phonological word forms can be used to support n-back performance, even when the phonological loop might be disrupted.

I had also predicted that PWA would perform with equal accuracy under both baseline and articulatory suppression conditions for unnameable stimuli and block stimuli, and that NI would perform with equal accuracy for block stimuli under both conditions. Such findings would have suggested that when participants are unable to retrieve phonological word forms, articulatory suppression does not impact their ability to complete the n-back task. These results were confirmed, and indicated that under the articulatory suppression condition, neither PWA nor NI experienced decreased accuracy for these stimulus types. Juxtaposing these results with those for nameable stimuli, it remains unclear if PWA are unable to employ the WM phonological loop to support n-back performance. They may still have available a language strategy to complete the task.

I will provide two possible explanations for these findings. The first supports the hypothesis that the phonological loop is not used in the n-back task. PWA and NI may be able to successfully complete the task by accessing language at the conceptual pre-lexical level. This explanation is consistent with Mayer and Murray's suggestion that an n-back task using linguistic stimuli can be executed using only "conceptual and/ or lemma level retrieval" (Mayer and Murray, 2012, page 336). Similarly, Pitman and Ruscin (2009) found no significant difference between baseline and articulatory suppression conditions, suggesting that their subjects were able to execute an n-back task without employing the phonological loop. An alternative explanation may be that both PWA with impaired word retrieval and NI individuals can complete n-back tasks using the visuospatial sketchpad to support WM. Baddeley (2007) hypothesized that access to the phonological loop may be unavailable if images cannot be converted to images with semantic, and hence phonological representations. If this is true, participants likely used the visuospatial sketchpad for both the object and block stimuli.

A second explanation for these results is that the phonological loop is used during n-back task performance but is not impacted by articulatory suppression. Articulatory suppression is a highly repetitive task. It seems possible that it does not require retrieving the phonological word form for successive productions, for identical utterances (i.e., repeating “Monday”) nor does it require repetitive speech motor programming. It may only require repetitive speech motor execution, which may not be very taxing. Hence, participants may have been able to continue retrieving lemmas, and likely even phonological word forms, even as articulatory suppression utterances continue to cycle in a speech motor buffer. If so, as suggested by anecdotal evidence from the NI group who indicated they were able to continue naming objects under the articulatory suppression condition, phonological encoding can be used for n-back performance without being disrupted by articulatory suppression.

General conclusions

Results indicated that the PWA group presented with decreased WM capacity when compared to the NI group, particularly for 1-back tasks. For both groups, WM capacity was impaired in a predominantly load-dependent manner, with significant differences in the direction of n=0 > n=2. Overt naming ability did not align with WM performance. I hypothesize that this lack of results is because either successful n-back performance can be supported at the conceptual pre-lexical level, or that participants were able to use the visuospatial sketchpad to support successful performance. Disruption of the phonological loop did not impact WM performance. Lack of significant findings between baseline and articulatory suppression conditions suggest that either the phonological loop is not taxed during the n-back task, or that articulatory suppression does not significantly disrupt the phonological loop enough to decrease accuracy.

While it is unclear which WM process was responsible for deficits seen in the PWA group and at the 2-back level, a WM deficit may contribute to language-processing impairments in the PWA group. If PWA are attempting to use verbal mediation to guide their thoughts and behavior, their ability to use covert language may be impacted by concomitant WM deficits and degraded performance associated with subtle changes in processing load. Intact word retrieval may not support the use of verbal mediation to facilitate WM performance; however, PWA may employ the visuospatial sketchpad to support WM when lexical retrieval fails. Results also align with anecdotal evidence from PWA that they have access to inner language even when they have difficulty communicating with others.

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Appendices

Appendix A: Individualized linguistic stimuli

Participant	**Readily Nameable Stimuli**	**Kucera-Francis Frequency Counts**	**Unnameable Stimuli**	**Kucera-Francis Frequency Counts**
PWA1	Book	193	Bus	34
	Gun	118	Corn	34
	Key	88	Barn	29
	Train	82	Belt	29
	Moon	60	Glasses	29
	Tree	59	Cloud	28
	Hat	56	Pot	28
	Shirt	27	Cap	27
		High=193 *Low=27* *Mean=85.38*		*High=34* *Low=27* *Mean=29.75*
PWA2	Table	198	Train	82
	Book	193	Bottle	76
	Heart	173	Moon	60
	Window	119	Ring	47
	Gun	118	Coat	43
	Sun	112	Bus	34
	Ball	110	Cloud	28
	Key	88	Pot	28
		High=198 *Low=88* *Mean=138.88*		*High=82* *Low=28* *Mean=49.75*
PWA3	Book	193	Wheel	56
	Bed	127	Coat	43

	Window	119	Jacket	33
	Gun	118	Mountain	33
	Ball	110	Barn	29
	Glass	99	Belt	29
	Key	88	Cloud	28
	Train	82	Shirt	27
		High=193 *Low=82* *Mean=117.00*		*High=56* *Low=27* *Mean=34.75*
PWA4	Table	198	Wagon	55
	Book	193	Chain	50
	Heart	173	Coat	43
	Bed	127	Iron	43
	Window	119	Mountain	33
	Gun	118	Fence	30
	Sun	112	Cloud	28
	Ball	110	Star	25
		High=198 *Low=110* *Mean=143.75*		*High=55* *Low=25* *Mean=38.38*
	High Frequency Stimuli	**Kucera-Francis Frequency Counts**	**Low Frequency Stimuli**	**Kucera-Francis Frequency Counts**
NI1	Table	198	Mountain	33
	Book	193	Fence	30
	Heart	173	Barn	29
	Bed	127	Belt	29
	Window	119	Glasses	29
	Gun	118	Cloud	28
	Sun	112	Shirt	27
	Ball	110	Star	25

		High=198 *Low=110* *Mean=143.75*		*High=33* *Low=25* *Mean=28.75*
NI2	Table	198	Fence	30
	Book	193	Barn	29
	Heart	173	Belt	29
	Bed	127	Glasses	29
	Window	119	Cloud	28
	Gun	118	Pot	28
	Sun	112	Cap	27
	Ball	110	Star	25
		High=198 *Low=110* *Mean=143.75*		*High=30* *Low=25* *Mean=28.13*
NI3	Table	198	Iron	43
	Book	193	Football	36
	Bed	127	Bus	34
	Sun	112	Jacket	33
	Ball	110	Glasses	29
	Key	88	Cloud	28
	Train	82	Cap	27
	Knife	76	Star	25
		High=198 *Low=76* *Mean=123.25*		*High=43* *Low=25* *Mean=31.88*
NI4	Table	198	Mountain	33
	Book	193	Fence	30
	Heart	173	Barn	29
	Bed	127	Belt	29
	Window	119	Glasses	29

	Sun	112	Cloud	28
	Ball	110	Cap	27
	Glass	99	Star	25
		High=198 *Low=99* *Mean=141.38*		*High=33* *Low=25* *Mean=28.75*

Appendix B: Order of administration of experimental n-back tasks

Order	**Load**	**PWA1 & NI1**	**PWA2 & NI2**	**PWA3 & NI3**	**PWA4 & NI4**
		Baseline	*Suppression*	*Baseline*	*Suppression*
1	n=0	Blocks	Blocks	Blocks	Blocks
2	n=0	Unnameable/ Low Frequency	Unnameable/ Low Frequency	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency
3	n=0	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency	Unnameable/ Low Frequency	Unnameable/ Low Frequency
		Suppression	*Baseline*	*Suppression*	*Baseline*
4	n=0	Blocks	Blocks	Blocks	Blocks
5	n=0	Unnameable/ Low Frequency	Unnameable/ Low Frequency	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency
6	n=0	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency	Unnameable/ Low Frequency	Unnameable/ Low Frequency
		Baseline	*Suppression*	*Baseline*	*Suppression*
7	n=1	Blocks	Blocks	Blocks	Blocks
8	n=1	Unnameable/ Low Frequency	Unnameable/ Low Frequency	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency
9	n=1	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency	Unnameable/ Low Frequency	Unnameable/ Low Frequency
		Suppression	*Baseline*	*Suppression*	*Baseline*
10	n=1	Blocks	Blocks	Blocks	Blocks
11	n=1	Unnameable/ Low Frequency	Unnameable/ Low Frequency	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency
12	n=1	Readily Nameable/	Readily Nameable/	Unnameable/	Unnameable/

		High Frequency	High Frequency	Low Frequency	Low Frequency
		Baseline	*Suppression*	*Baseline*	*Suppression*
13	n=2	Blocks	Blocks	Blocks	Blocks
14	n=2	Unnameable/ Low Frequency	Unnameable/ Low Frequency	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency
15	n=2	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency	Unnameable/ Low Frequency	Unnameable/ Low Frequency
		Suppression	*Baseline*	*Suppression*	*Baseline*
16	n=2	Blocks	Blocks	Blocks	Blocks
17	n=2	Unnameable/ Low Frequency	Unnameable/ Low Frequency	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency
18	n=2	Readily Nameable/ High Frequency	Readily Nameable/ High Frequency	Unnameable/ Low Frequency	Unnameable/ Low Frequency

Appendix C: Raw data for hits and false alarms (hits [x/15], false alarms [y/33])

	n=0			**n=1**			**n=2**		
	Readily Nameable/ High Frequency	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**
Baseline									
PWA1	11,0	15,0	15, 6	11,0	1,2	8,6	8,1	7,3	7,6
PWA2	15,0	15,0	12,0	7,1	10,0	11,1	7,1	8,4	6,7
PWA3	15,0	14,1	14,2	12,0	12,0	12,1	6,6	9,2	2,6
PWA4	15,0	15,0	15,0	13,0	10,0	10,0	7,2	10,3	4,6
NI1	13,0	15,0	14,0	14,0	13,0	14,1	13,0	9,0	6,0
NI2	15,0	15,0	14,0	15,0	15,0	15,1	11,0	14,0	11,2
NI3	15,0	15,0	14,0	15,1	15,0	13,0	12,1	13,0	6,1
NI4	15,0	15,0	15,3	15,0	15,0	15,0	7,1	10,1	3,1
Articulatory Suppression									
PWA1	15,0	15,0	15,9	14,0	15,0	14,1	7,1	5,4	7,8
PWA2	15,2	15,0	13,0	11,2	10,1	10,2	6,0	4,1	5,7
PWA3	15,0	15,0	13,3	12,1	9,0	12,0	9,4	12,5	5,9
PWA4	15,0	15,1	13,0	7,0	11,0	10,0	5,0	6,1	3,1
NI1	15,0	15,0	15,1	15,0	14,0	15,1	15,0	5,1	6,2
NI2	15,0	15,0	15,0	15,1	13,0	15,1	14,0	14,0	10,1
NI3	15,0	15,0	14,0	14,0	14,0	13,0	10,1	10,1	2,2
NI4	15,0	15,1	14,0	15,1	13,0	14,4	5,1	10,3	1,2

Appendix D: RT-hits data

	n=0			**n=1**			**n=2**		
	Readily Nameable / High Frequency	**Unnameable / Low Frequency**	**Blocks**	**Readily Nameable / High Frequency**	**Unnameable / Low Frequency**	**Blocks**	**Readily Nameable / High Frequency**	**Unnameable / Low Frequency**	**Blocks**
Baseline									
PWA1	451.55	452.53	513.67	769.91	351.00	722.88	710.63	799.43	623.29
PWA2	712.60	482.53	624.75	564.00	515.90	505.55	872.00	1108.50	1015.17
PWA3	488.47	546.14	659.07	463.58	604.59	552.25	924.83	748.22	849.00
PWA4	623.32	640.00	617.07	649.08	757.40	831.50	807.71	772.50	782.00
NI1	527.53	477.80	684.65	668.58	631.31	617.27	782.38	779.33	878.67
NI2	434.40	420.27	476.86	463.33	416.20	421.33	476.91	517.07	571.73
NI3	414.13	557.07	690.50	529.27	491.40	522.69	829.42	664.38	1119.17
NI4	361.00	415.33	523.07	440.73	463.67	463.20	713.29	693.00	881.00
A.S.									
PWA1	451.13	453.53	489.53	489.64	630.47	886.86	654.14	1202.20	533.00
PWA2	523.67	561.00	1011.00	606.27	421.10	560.90	961.50	800.00	1111.00
PWA3	459.87	505.27	608.00	531.92	511.56	527.17	554.89	740.33	616.60
PWA4	634.47	665.80	630.00	705.71	770.09	776.50	982.60	960.00	1052.33
NI1	426.07	459.80	532.20	549.07	519.79	523.67	604.27	438.60	726.17
NI2	421.20	412.07	459.93	423.80	411.38	440.80	420.93	509.29	577.40
NI3	592.87	601.87	621.86	511.50	588.43	613.08	780.90	738.90	961.00
NI4	409.20	426.13	513.50	424.53	456.85	483.43	564.80	536.30	631.00

Appendix E: RT-false alarms data

	n=0			**n=1**			**n=2**		
	Readily Nameable / High Frequency	**Unnameable / Low Frequency**	**Blocks**	**Readily Nameable / High Frequency**	**Unnameable / Low Frequency**	**Blocks**	**Readily Nameable / High Frequency**	**Unnameable/ Low Frequency**	**Blocks**
Baseline									
PWA1			550.33		611.50	469.67	2015.00	912.33	811.67
PWA2				480.00		509.00	794.00	1092.00	892.71
PWA3		358.00	606.00			671.00	881.50	634.50	719.33
PWA4							856.00	686.00	1277.50
NI1						526.00			
NI2						455.00			859.50
NI3				604.00			1602.00		149.00
NI4			480.33				672.00	675.00	26.00
A.S.									
PWA1			479.89			898.00	475.00	1178.25	616.50
PWA2	594.00			594.00	247.00	363.50		2098.00	761.86
PWA3			612.67	659.00			651.50	827.60	708.44
PWA4		476.00						583.00	955.00
NI1			510.00			672.00		847.00	845.50
NI2				457.00		412.00			754.00
NI3							1038.00	847.00	1555.50
NI4		306.00	416.00	578.00		492.75	452.00	554.33	739.00

Appendix F: Post-experiment interview questions

1. How do you think you did on the memory tasks?
2. Did you use a strategy to help you remember the objects?
    a. If yes, what strategy did you use?
    b. If yes, do you think this strategy helped you remember the objects?
    c. If no, did you try to name the objects?
3. Did you try to name the blocks?
4. Did saying “Monday” make the memory tasks harder?
5. Did you use a strategy to help you compensate for saying “Monday”?
6. Did you try to name the objects while saying “Monday” to help you remember them?

Appendix G: Results for permutation tests

Condition	**Load**	**Stimulus Type**	**Significance***	**Comparison**
Baseline	n=0	Readily Nameable/ High Frequency	n.s.	
	n=0	Unnameable/ Low Frequency	n.s.	
	n=0	Blocks	n.s.	
	n=1	Readily Nameable/ High Frequency	<2%	NI > PWA
	n=1	Unnameable/ Low Frequency	<2%	NI > PWA
	n=1	Blocks	<2%	NI > PWA
	n=2	Readily Nameable/ High Frequency	n.s.	
	n=2	Unnameable/ Low Frequency	<2%	NI > PWA
	n=2	Blocks	<2%	NI > PWA
Articulatory Suppression				
	n=0	Readily Nameable/ High Frequency	n.s.	
	n=0	Unnameable/ Low Frequency	n.s.	
	n=0	Blocks	<3%	NI > PWA
	n=1	Readily Nameable/ High Frequency	<6%	NI > PWA
	n=1	Unnameable/ Low Frequency	<5%	NI > PWA
	n=1	Blocks	<6%	NI > PWA
	n=2	Readily Nameable/ High Frequency	n.s.	
	n=2	Unnameable/ Low Frequency	n.s.	
	n=2	Blocks	n.s.	

Note. * denotes the percent chance the observed data falls within the region of rejection., i.e., was not obtained by chance.

Appendix H: Results for Friedman's Two-Way Analysis of Variance by Ranks test

Condition	**Group**	**n- or Stimulus Type**	**Differences Among Stimuli**		**Differences Among n-**	
			Fr	**Significance**	**Fr**	**Significance**
Baseline	PWA	n=0	0.88	n.s.		
		n=1	0.88	n.s.		
		n=2	6.00	n.s. (a=.10)		
		Readily Nameable			6.14	n.s. (a=.10)
		Unnameable			6.50	a = .05
		Blocks			8.00	a = .01
	NI	n=0	2.38	n.s.		
		n=1	0.88	n.s.		
		n=2	3.50	n.s.		
		High Frequency			6.13	n.s. (a=.10)
		Low Frequency			3.50	n.s.
		Blocks			3.50	n.s.
Articulatory Suppression	PWA	n=0	6.00	n.s. (a=.10)		
		n=1	1.50	n.s.		
		n=2	3.38	n.s.		
		Readily Nameable			8.00	a=.01
		Unnameable			7.13	a=.05
		Blocks			6.13	n.s. (a=.10)

	NI	n=0	6.13	n.s. (a=.10)		
		n=1	0.13	n.s.		
		n=2	3.50	n.s.		
		High Frequency			3.88	n.s.
		Low Frequency			6.50	a=.05
		Blocks			4.63	n.s.

Appendix I: Results for Friedman's test for multiple comparisons

			Comparison
Baseline	PWA	Unnameable	n=0 > n=2
		Blocks	n=0 > n=2
Articulatory Suppression	PWA	Readily Nameable	n=0 > n=2
		Unnameable	n=0 > n=2
	NI	Low Frequency	n=0 > n=2

Note. Value required for significance for all comparisons = 6.77. Alpha set at .05 for all comparisons.

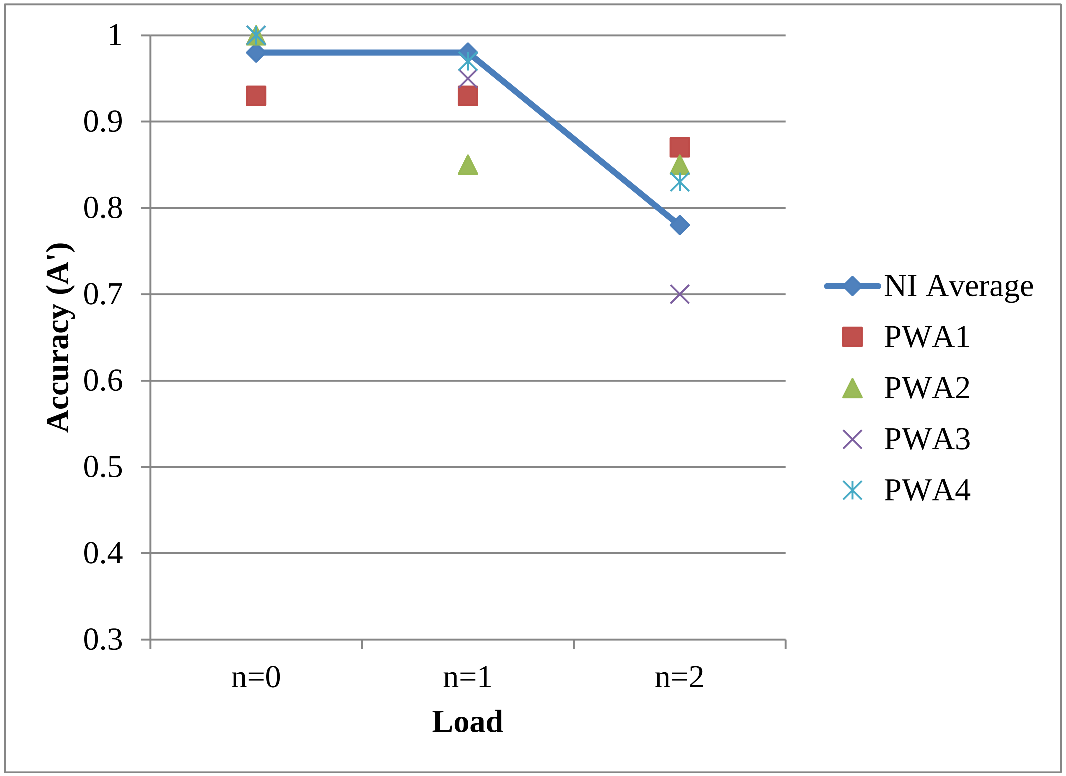
Appendix J: Results for Crawford's one-tailed t-test

	n=0			**n=1**			**n=2**		
	Readily Nameable/ High Frequency	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**	**Readily Nameable/ High Frequency**	**Unnameable/ Low Frequency**	**Blocks**
Baseline									
PWA1	-0.89	0	-3.58*	-4.47**	-21.02**	-9.39 **	0.34	-2.50*	-1.49
PWA2	0.68	0	-3.58*	-11.63**	-3.13*	-2.68*	0.26	-2.33	-2.39
PWA3	0.68	-26.83**	-1.79	-2.68*	-1.79	-1.79	-0.30	-1.25	-6.71 **
PWA4	0.68	0	0.89	-0.89	-3.13*	-2.68*	0.19	-1.25	-3.43*
Articulatory Suppression									
PWA1	0	0	-0.67	0.30	1.79	-0.45	0.33	-1.9	-0.16
PWA2	-17.89**	0	0.22	-1.79	-7.16**	-4.03 **	0.33	-1.23	-0.47
PWA3	0	0	-0.45	-0.60	-7.16**	-1.79	-0.43	0	0.63
PWA4	0	-8.94**	-2.01	-2.98*	-4.47**	-2.68*	0.27	-0.67	0.21

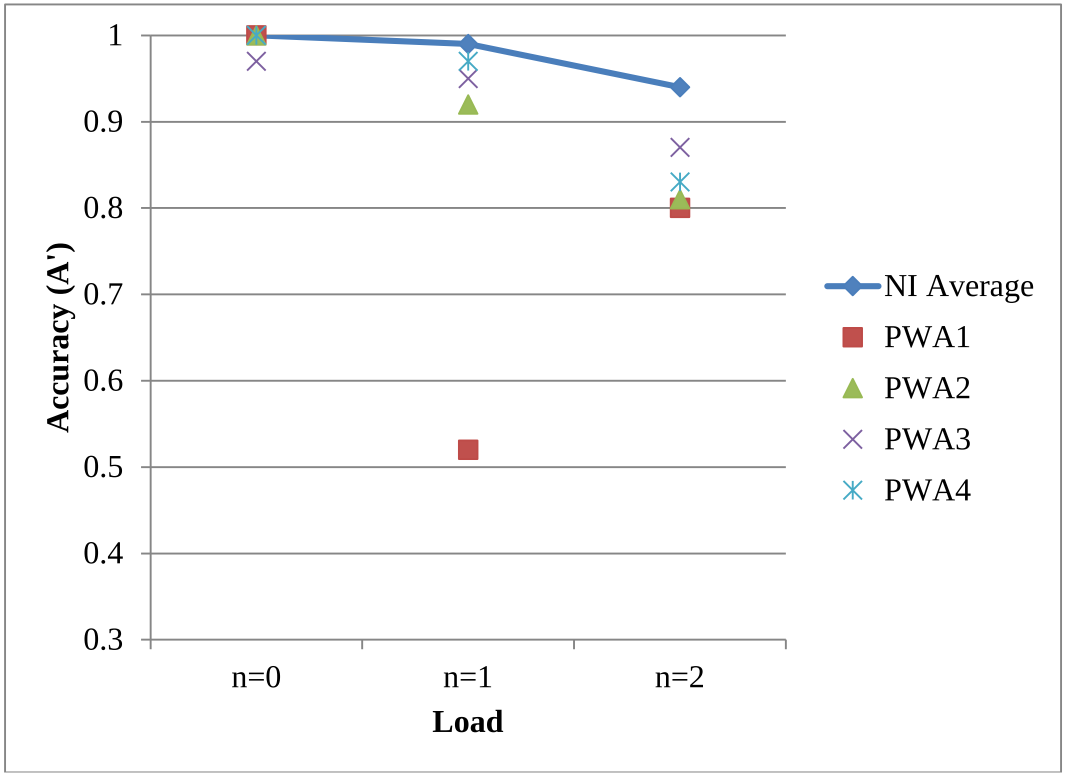
Note. * denotes p<.05, ** denotes p≤.01 when compared to the NI average.

Appendix K: Crawford's t-test figures

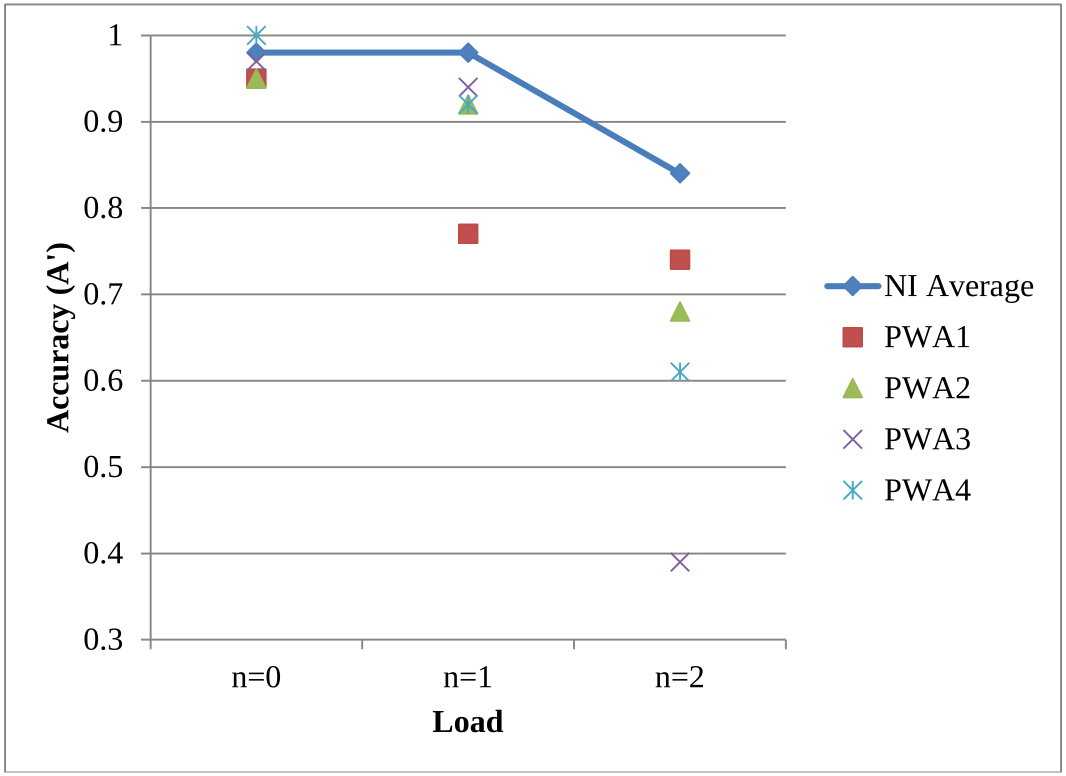
<u>Baseline</u>



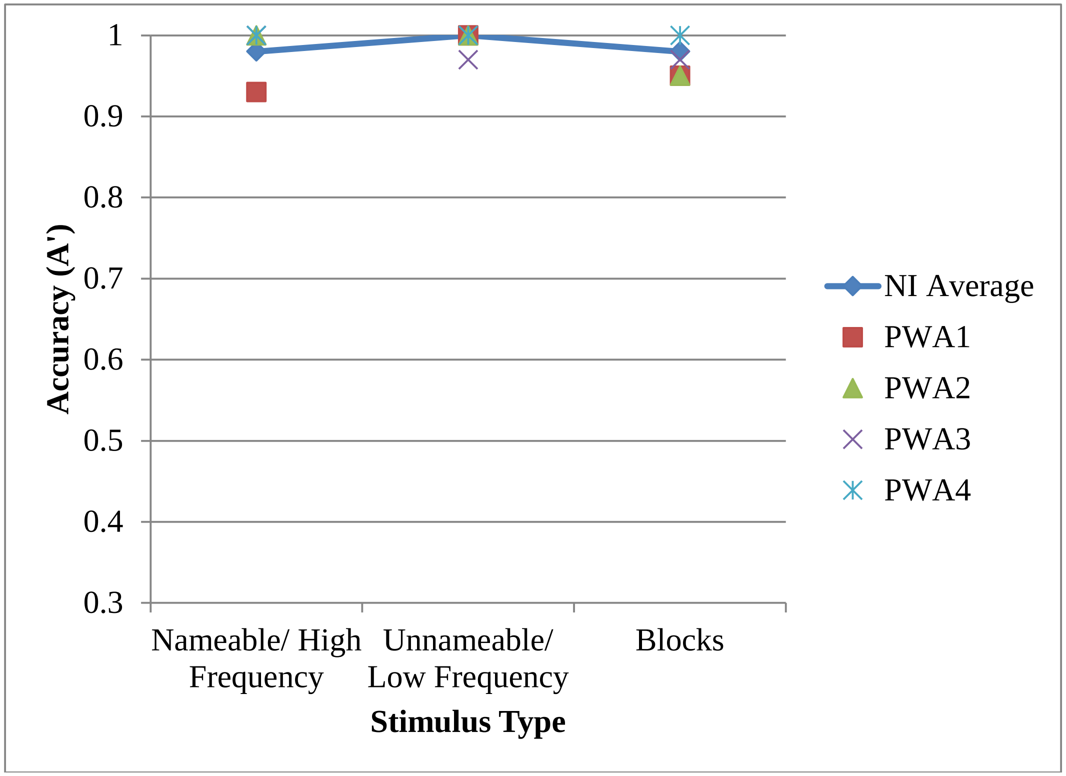
Individual A' scores for PWA participants compared to the mean A' for NI participants for readily nameable/ high frequency stimulus types under the baseline condition.



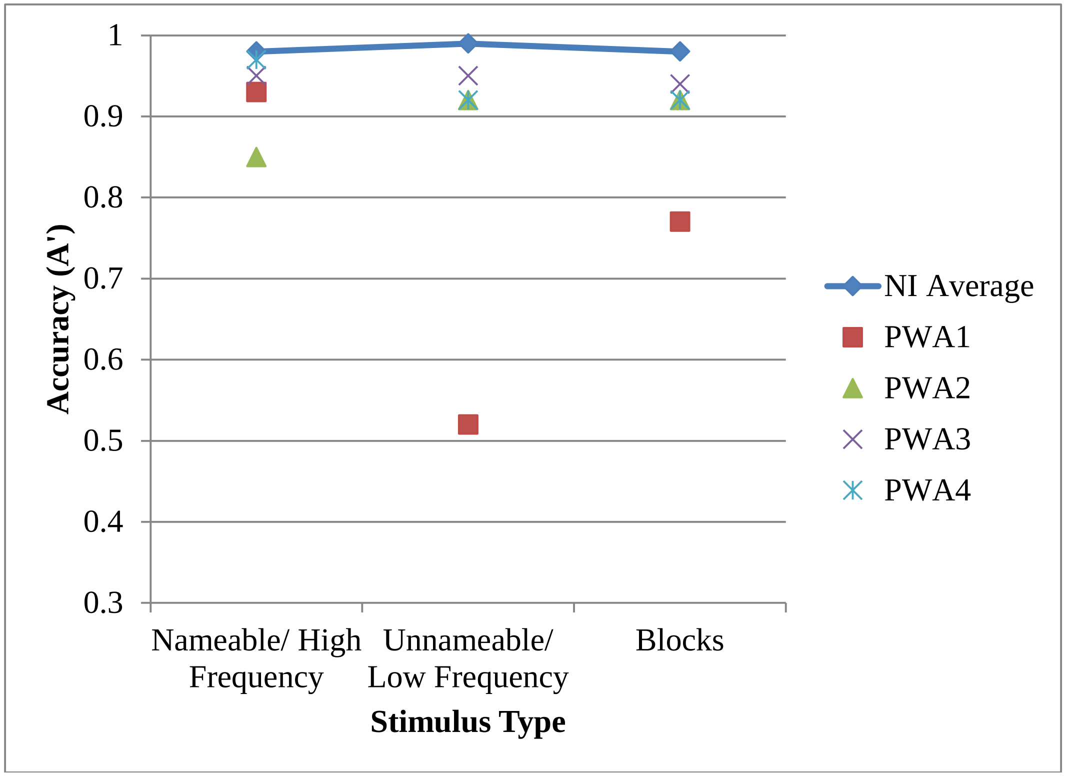
Individual A' scores for PWA participants compared to the mean A' for NI participants for unnameable/ low frequency stimulus types under the baseline condition.



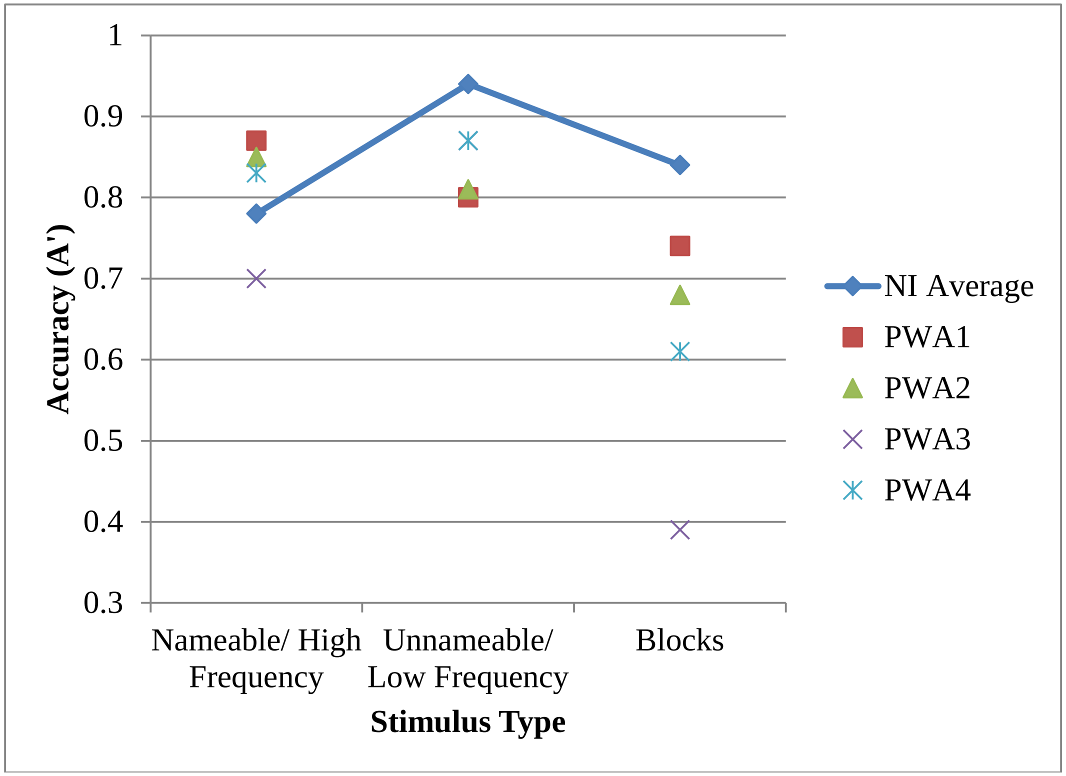
Individual A' scores for PWA participants compared to the mean A' for NI participants for the block stimulus type under the baseline condition.



Individual A' scores for PWA participants compared to the mean A' for NI participants for n=0 load level under the baseline condition.

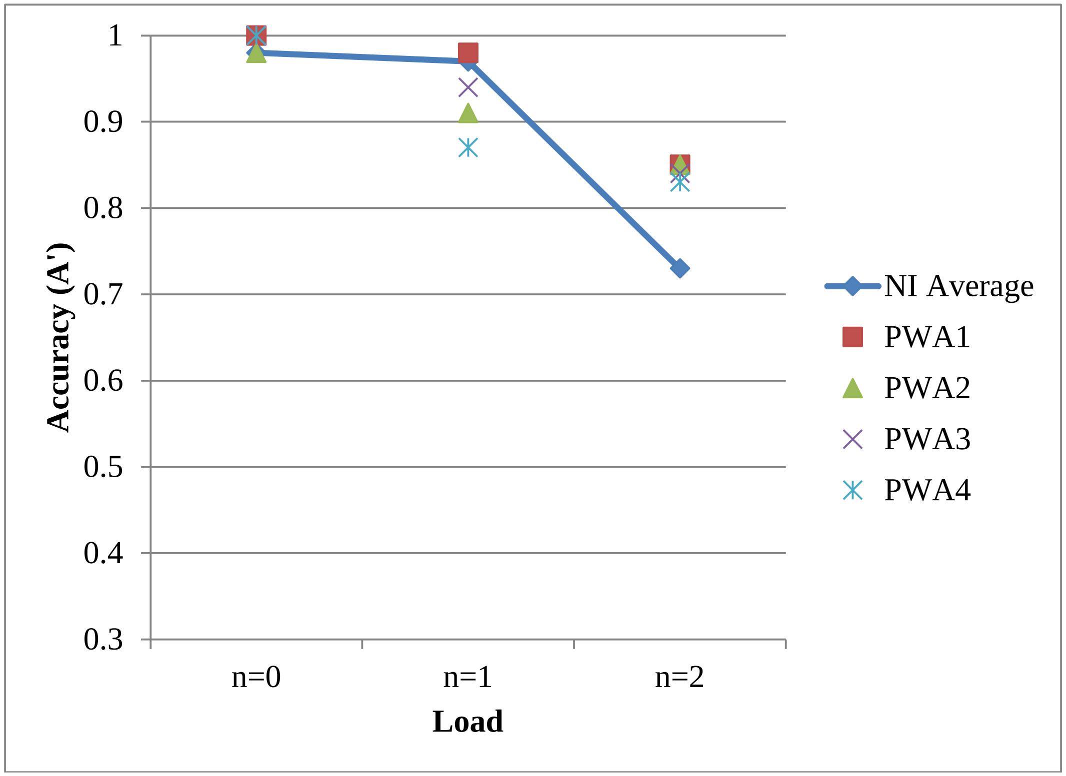


Individual A' scores for PWA participants compared to the mean A' for NI participants for n=1 load level under the baseline condition.

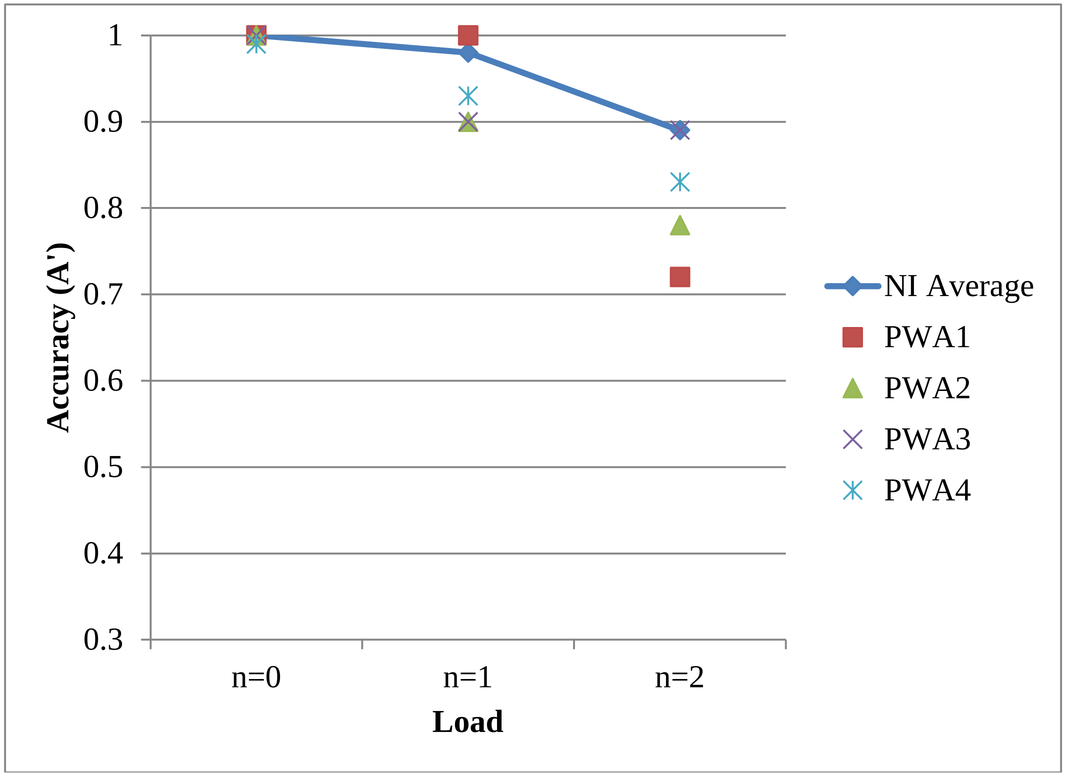


Individual A' scores for PWA participants compared to the mean A' for NI participants for n=2 load level under the baseline condition.

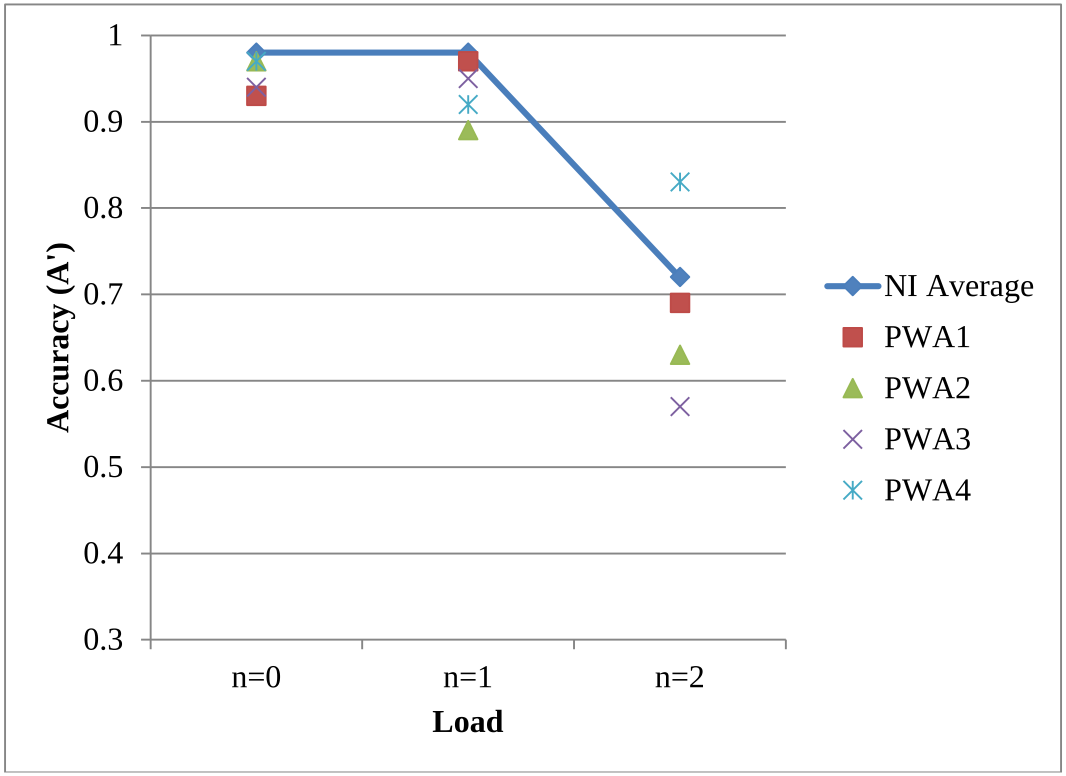
Articulatory Suppression



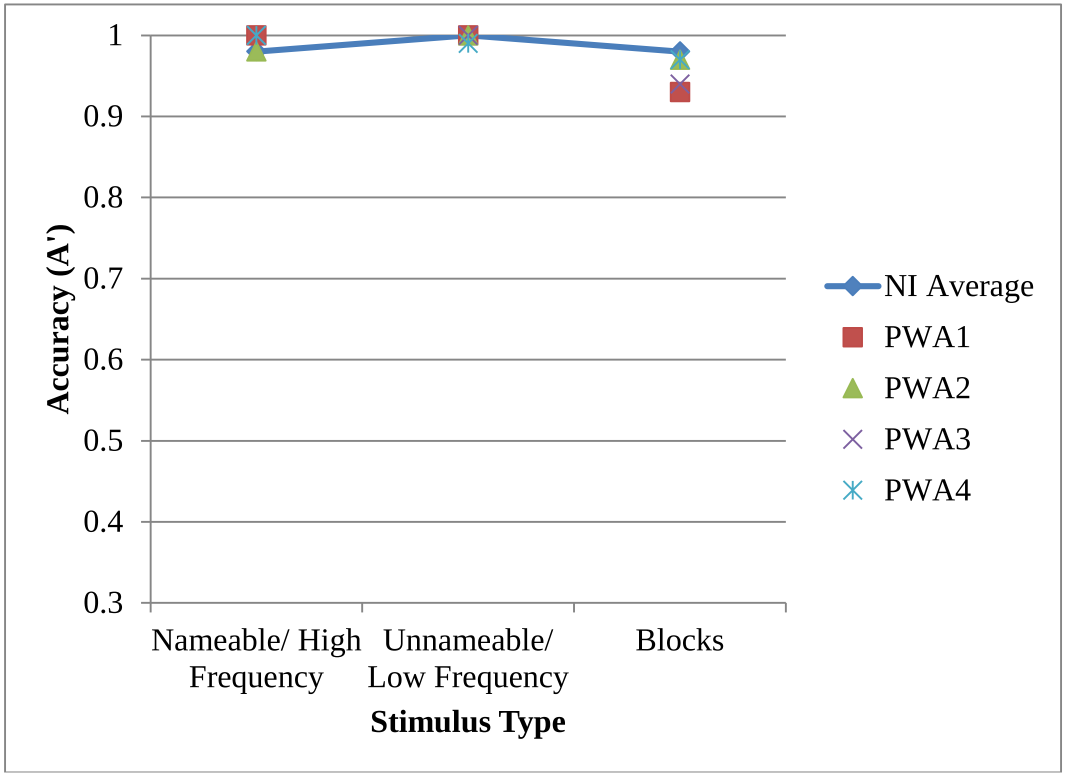
Individual A' scores for PWA participants compared to the mean A' for NI participants for readily nameable/ high frequency stimulus types under the articulatory suppression condition.



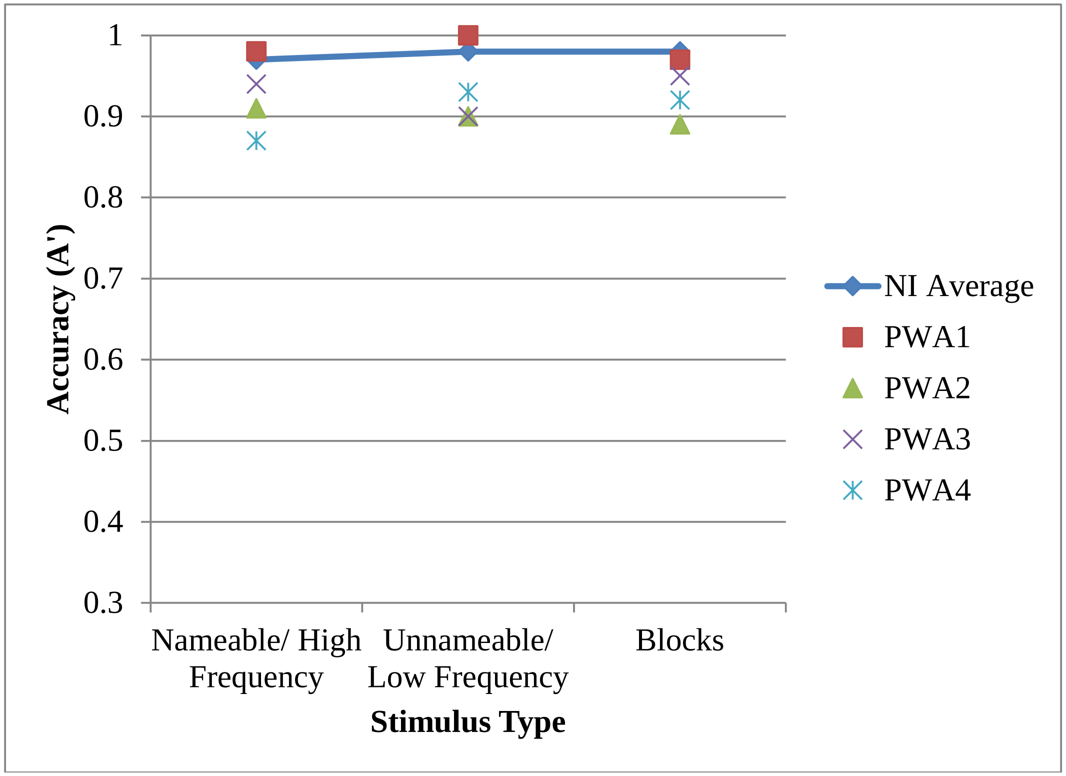
Individual A' scores for PWA participants compared to the mean A' for NI participants for unnameable/ low frequency stimulus types under the articulatory suppression condition.



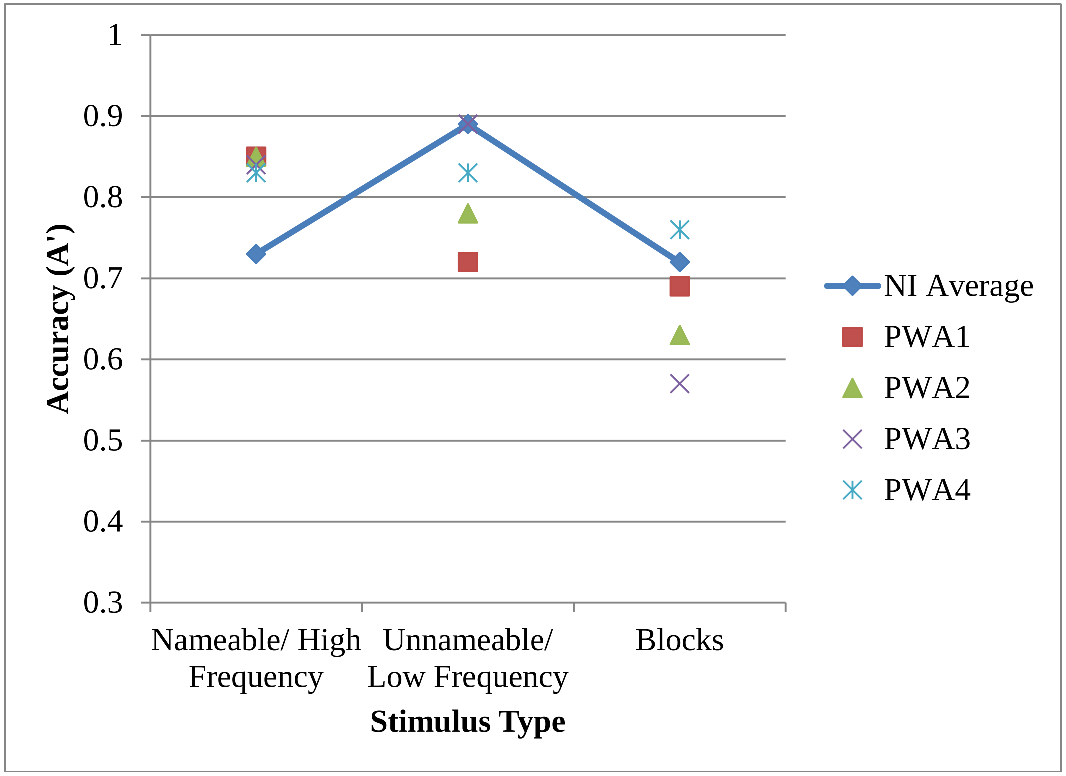
Individual A' scores for PWA participants compared to the mean A' for NI participants for the block stimulus type under the articulatory suppression condition.



Individual A' scores for PWA participants compared to the mean A' for NI participants for n=0 load level under the articulatory suppression condition.



Individual A' scores for PWA participants compared to the mean A' for NI participants for n=1 load level under the articulatory suppression condition.



Individual A' scores for PWA participants compared to the mean A' for NI participants for n=2 load level under the articulatory suppression condition.

Appendix L: Post-experiment interview responses (paraphrased)

PWA1: Reported 50/50 performance on the tasks (unspecified). He tried to name the objects, but did not think his naming attempts were successful. He did not try to name the blocks. Saying “Monday” made all tasks more difficult. He did not try to compensate nor did he try to name the objects while saying “Monday.”

PWA2: Reported that 2-back tasks were the most difficult. She tried to name the objects, and reported that it helped. She also tried to name the blocks. Saying “Monday” made the block tasks more difficult. She did not try to compensate nor did she try to name the objects while saying “Monday.”

PWA3: Reported that 2-back tasks were the most difficult. He tried to name the objects, but was unable to do so during the 2-back tasks. He did not try to name the blocks. Saying “Monday” made all tasks more difficult. He did not try to compensate. He continued trying to name the objects, but with increased difficulty.

PWA4: Reported that all tasks were difficult. He did not try to name the objects; he tried to visualize them, but did not think his strategy helped. He tried to assign a name to the rotation of the blocks. Saying “Monday” made all tasks more difficult. He tried to compensate by using the metronome, and he continued trying to name the objects.

NI1: Reported that 2-back tasks were the most difficult. She tried to name the objects during the 2-back tasks, and reported that it helped. She reported that each time she hit the laptop computer spacebar she lost track of the objects she had seen prior. She did not try to name the blocks. Saying “Monday” made the 2-back tasks and block tasks more difficult. She did not try to compensate. She continued trying to name the objects.

NI2: Reported that blocks were the most difficult. She reported that she tried to name the objects, but that it slowed her down, so instead she tried to visualize them. She reported trying to visually orient the blocks on one side (i.e., up, down) but did not think her attempts were successful. Saying “Monday” made all tasks more difficult initially, but after awhile the effects of saying “Monday” wore off and she wasn’t aware she was saying it. She did not try to compensate nor did she try to name the objects while saying “Monday.”

NI3: Reported that 2-back tasks and blocks were the most difficult (2-back blocks being the hardest), and that the second half of testing was more difficult. He used the 1-word description he gave during the VCN task to name the objects. He tried to name the blocks on his last attempt, but reported that his strategy was unsuccessful – he tried to count the number of blocks and their angles (i.e., “low-2”, “up-3”) but it took too long to come up with a description and he couldn’t remember the description long enough for it to be useful. Saying “Monday” made all tasks more difficult, particularly the blocks. He tried to compensate by tapping his foot, and he continued trying to name the objects.

NI4: Reported not knowing how he did on the memory tasks. He did not try to use a verbal or visual strategy, but still tried to answer to the best of his ability. He did not try to name the objects, nor did he try to name the blocks. He reported that he didn’t think naming the objects or blocks would have helped. Saying “Monday” was somewhat distracting and wore him down – he reported being tired by the end. He did not try to compensate nor did he try to name the objects while saying “Monday."