

## Supplement Article

# Nonverbal Working Memory as a Predictor of Anomia Treatment Success

Stacy M. Harnish<sup>a</sup> and Jennifer P. Lundine<sup>a</sup>

**Purpose:** The purpose of the study was to determine (a) reliability of the spatial span as a nonverbal working memory (WM) task in individuals with aphasia, (b) whether participation in anomia treatment changed spatial span scores, and (c) the degree to which visuospatial WM predicted response to anomia treatment.

**Method:** Eight individuals with chronic aphasia were repeatedly assessed on the forward and backward conditions of the spatial span over 4 weeks while undergoing treatment for anomia. Experiment 1 assessed reliability of the spatial span conditions and determined whether span scores changed after beginning anomia treatment. Experiment 2 investigated

the spatial span as a predictor of anomia treatment success.

**Results:** Results of Experiment 1 showed that 7 participants demonstrated stability of the forward condition of the spatial span, and 5 participants demonstrated stability of the backward condition across all sessions ( $p = .05$ ). No participants showed an effect of aphasia treatment on span performance in either condition. Experiment 2 found that the backward span condition significantly predicted anomia treatment effect size,  $F(1, 6) = 15.202, p = .008$ .

**Conclusions:** Visuospatial WM abilities were highly predictive of response to anomia treatment, supporting an account of WM that includes a central processing mechanism.

Short-term memory refers to the ability to temporarily hold information in an accessible state (Atkinson & Shiffrin, 1968; Cowan, 2008). In some models of memory, short-term memory may be seen as a prerequisite to working memory (WM), whereby information that is temporarily held in short-term memory is monitored and manipulated to plan and carry out behavior (Cowan, 2008; Potagas, Kasselimis, & Evdokimidis, 2011). Working memory may involve retaining partial results while attending to or “working on” another aspect of the information, such as computing mental arithmetic (e.g., counting backwards from 100 by 7).

## Models of Working Memory in Healthy Individuals

Baddeley and Hitch (1974) proposed a model that separated WM into three subsystems: the central executive control system that provides attentional control of WM and its two slave systems, the phonological loop that processes verbal and acoustic information and the visuospatial sketchpad that processes visual information. A fourth

subsystem, the episodic buffer (Baddeley, 2000), was added later to account for the capacity to chunk information from different subsystems with information from long-term memory (Baddeley, 2003)—that is, the episodic buffer allows for the addition of a central storage mechanism that complements the peripheral stores (i.e., the phonological loop and visuospatial sketchpad). Thus, Baddeley and Hitch’s model posits that verbal and nonverbal WM are processed in two distinct peripheral systems, albeit with attentional oversight from the same central executive system and with assistance from a central processing and storage mechanism—the episodic buffer—to integrate WM between the two peripheral systems and with long-term memory.

Cowan’s embedded processes model (Cowan, 1988) posits that short-term memory storage is a temporarily activated subset of information from long-term memory. A portion of this activated short-term memory becomes the focus of attention, as controlled by a central executive process (i.e., attentional control). The *central executive* process refers to the voluntary control of information transfer from one form of storage to another, such as from long-term memory to short-term memory or vice versa. Components of WM include activated short-term memory and the focus of attention within that memory, as well as central executive processes that control attention to manipulate the stored information (Cowan, 2008). Thus, this model assumes a hierarchically organized memory system

<sup>a</sup>The Ohio State University, Columbus

Correspondence to: Stacy M. Harnish, harnish.18@osu.edu

Editor: Anastasia Raymer

Associate Editor: Nadine Martin

Received September 15, 2014

Revision received February 23, 2015

Accepted May 6, 2015

DOI: 10.1044/2015\_AJSLP-14-0153

**Disclosure:** The authors have declared that no competing interests existed at the time of publication.

whereby portions of long-term memory activate during short-term memory, usually as a result of some outside stimulus. The focus of attention within activated short-term memory in combination with central executive oversight allows for WM processing. Differences in WM abilities may be due to the ability to control attention (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Bleckley, Conway, & Engle, 2001), inhibit irrelevant information (Gernsbacher, 1993; Lustig, May, & Hasher, 2001), narrow attention to ignore interference, expand attention to try to retain as many items as possible, or combine both narrowed and expanded attention to avoid interference while also remembering multiple items (Cowan, Fristoe, Elliott, Brunner, & Saults, 2006).

Although initially there were stark differences between Baddeley's and Cowan's models, they have become more similar through the years, suggesting that the field is making progress in establishing a more comprehensive model of WM (Cowan, Saults, & Blume, 2014). Cowan's model initially proposed only one central storage medium that contained information about features of items in memory, such as acoustic, phonological, orthographic, or lexical/semantic for verbal stimuli (Cowan, 1988, 1997). However, recent evidence supports the hypothesis that stimuli may be held in peripheral stores that are "nonattentional in nature" (Cowan et al., 2014, p. 1831). Cowan defined these nonattentional stores as those characterized by the absence of flexibility to trade storage from one modality in order to gain storage in another modality. Similarly, Baddeley's model (Baddeley & Hitch, 1974) separated WM into two peripheral processing and storage components but has evolved to include the episodic buffer (Baddeley, 2000) to supplement the phonological and visuospatial stores by holding chunks of information and binding or integrating information between stores. Hence, both Baddeley's model and Cowan's model now include peripheral and central processing components that are overseen by attentional control. The degree to which information processed and stored in peripheral components accesses attentional control mechanisms may vary depending on the peripheral components (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). There is a theoretical significance of both central and peripheral storage mechanisms in a WM model; these mechanisms may account for dissociations that point to modularity associated with peripheral stores (Friedman & Miyake, 2000; Shah & Miyake, 1996), as well as relationships between different stimulus modalities or types of code, or even a common mechanism underlying language and memory impairments (Martin, Saffran, & Dell, 1996; Potagas et al., 2011; Ricker, Cowan, & Morey, 2010), suggesting a shared processing or storage medium.

In addition to theoretical models of WM that would allow for central processing of both verbal and nonverbal information, brain imaging studies have pointed to a shared brain region responsible for storage of verbal and nonverbal information. The intraparietal sulcus has been implicated in underlying central storage of verbal and nonverbal stimuli, as well as nonmnemonic attentional processes (Cowan et al.,

2011; Hula & McNeil, 2008; Todd & Marois, 2004; Xu & Chun, 2006). This area has been proposed to act as a hub with functional connections to other brain regions (Anderson, Ferguson, Lopez-Larson, & Yurgelun-Todd, 2010; Majerus et al., 2006) that would provide input for information to be stored. Thus, both verbal and nonverbal WM appear to share at least one overlapping brain region that allows for central memory storage.

### *WM in Individuals With Aphasia*

It has been well established that individuals with aphasia tend to have difficulty with verbal WM (Burgio & Basso, 1997; Potagas et al., 2011) and nonverbal WM (Burgio & Basso, 1997; Lang & Quitz, 2012; Mayer & Murray, 2012; Potagas et al., 2011; Seniow, Litwin, & Lesniak, 2009; Wright & Fergadiotis, 2012) that can influence linguistic and nonlinguistic processing. Individuals with aphasia also tend to have difficulty with attention and executive function (Caspari, Parkinson, LaPointe, & Katz, 1998; Glosser & Goodglass, 1990; Hula & McNeil, 2008; Korda & Douglas, 1997; Murray, 2012a; Villard & Kiran, 2015).

Nonverbal WM has been investigated in neurologically intact individuals and individuals with aphasia by using spatial span tasks (Ackerman, Beier, & Boyle, 2002; De Renzi & Nichelli, 1975; Engle et al., 1999; Hitch, Towse, & Hutton, 2001; King & Just, 1991; Potagas et al., 2011), such as the Corsi block-tapping task and the Spatial Span subtest of the Wechsler Memory Scale (Wechsler, 1997). During these tasks, an individual is instructed to touch a series of identical blocks in sequence after the test administrator. The length of the sequence increases over time to increase the load on short-term memory. Typically, spatial span tasks include a forward condition and a backward condition, determining whether the participant should touch the blocks in the same order as the test administrator or in the reverse order.

Performance on span tasks has been shown to predict language comprehension (King & Just, 1991), mathematics (Hitch et al., 2001), and general fluid intelligence (Ackerman et al., 2002; Engle et al., 1999) in individuals without language impairment. Individuals with left-hemisphere lesions and aphasia have been shown to perform worse than individuals with no aphasia (i.e., both healthy controls and individuals with right hemisphere lesions and no aphasia) on spatial span tasks and verbal digit span tasks (De Renzi & Nichelli, 1975; Lang & Quitz, 2012; Laures-Gore, Marshall, & Verner, 2011). The digit span task is similar to spatial span except that the participant repeats numbers in the same or reverse order instead of touching blocks.

To better understand how nonverbal WM is assessed using the spatial span task, let us consider a broad analysis of the forward and backward conditions. Both conditions are considered nonverbal because they do not rely on verbal input or output and are considered spatial memory tasks because they rely on one's ability to accurately maintain information about the location of visual stimuli. Completion

of the forward condition presumably requires the participant to see the examiner touch a series of blocks, hold the sequence in nonverbal short-term memory or WM via the visuospatial sketchpad, and reproduce the sequence by touching the blocks in the same order. It is thought that inhibitory processes related to attention may assist with suppression of previously activated sequences (Wright & Fergadiotis, 2012). The backward condition relies more heavily on WM, as it requires the participant to see the examiner touch a series of blocks, hold the sequence in the visuospatial sketchpad while manipulating it, and produce the manipulated sequence by touching the blocks in reverse order.

In general, healthy individuals and individuals with aphasia tend to perform better on the forward conditions of the digit span and spatial span than they do on backward conditions (Laures-Gore et al., 2011; Ween, Verfaellie, & Alexander, 1996). There has been some discussion in the literature about the degree to which span tasks engage different aspects of memory (Hester, Kinsella, & Ong, 2004; Kessels, van den Berg, Ruis, & Brands, 2008; Vandierendonck, Kemps, Fastame, & Szmalec, 2004). Kessels et al. (2008) compared verbal digit span performance in the forward and backward conditions to nonverbal spatial span performance in the forward and backward conditions in 246 healthy older adults. They found that the digit span backward was more difficult than the forward condition, but there was no difference between conditions on the spatial span. The authors proposed an explanation related to Baddeley's model of WM (Baddeley & Hitch, 1974) and suggested that digit span forward and backward conditions may rely on different cognitive operations: the forward digit span relying on the phonological loop, and the backward digit span relying on the phonological loop and the central executive system. The increased dependence on the central executive system may be the factor that makes the backward condition more difficult in healthy individuals. However, the spatial span may only rely on the visuospatial sketchpad in both forward and backward conditions, making the conditions more equitable.

Why would the backward condition of the digit span require the central executive system in addition to the phonological loop, but the backward condition of the spatial span require only the visuospatial sketchpad and no central executive system? It has been proposed that digit span requires attentional control during manipulation of the maintained digits because the stimuli to be manipulated are in the auditory modality and slowly decaying in WM (Cowan, 2008). In contrast, the nonverbal spatial span may not rely as heavily on attentional oversight because stimuli presented are always visible during forward and backward conditions, so only the path between the items needs to be recalled (Smyth & Scholey, 1992). An alternate view (Vandierendonck et al., 2004; Wilde, Strauss, & Tulskey, 2004) posits that both conditions of the spatial span rely on the central executive system equally. Thus, there is current debate regarding whether the forward and/or backward condition of the spatial span engages only peripheral processing

mechanisms (such as the visuospatial sketchpad proposed by Baddeley & Hitch, 1974), or whether attentional oversight via the executive control system also plays a part. Moreover, this discussion in the literature has been related to individuals without neurological impairment, raising the possibility that degree of reliance on attentional oversight to complete the task may not generalize to individuals with aphasia.

De Renzi and Nichelli (1975) argued that because digit span and spatial span performance in individuals with aphasia are both disrupted, speech and language abilities are not the only underlying factor affecting performance on digit span tasks. Instead, the ability to hold more information in short-term memory and WM before outputting the information is impaired. The extent to which these WM deficits affect recovery from aphasia is still under investigation.

### *The Relationship Between Nonverbal WM and Language Recovery With Treatment*

Baddeley's and Cowan's models of WM have evolved over the years. They now both include mechanisms to process information peripherally and/or centrally that can account for dissociations between modalities (Friedman & Miyake, 2000; Shah & Miyake, 1996), as well as relationships and interactions among modalities (Martin et al., 1996; Potagas et al., 2011; Ricker et al., 2010). Differences between processing of verbal and nonverbal information may tell us something about the processing demands of stimuli related to the modality of input. In healthy individuals, studies have shown discrepant results between verbal and nonverbal WM tasks, possibly indicating varying degrees of reliance upon attentional resources, such as central executive control mechanisms (Engle et al., 1999; Miyake et al., 2001). Research has shown that in the verbal domain, short-term memory and WM spans are related but distinguishable (Engle et al., 1999). As discussed, short-term memory spans involve simple storage-oriented span tasks with no explicit concurrent processing requirement, and WM refers to complex span tasks that involve storage as well as concurrent processing (Cowan, 2008; Potagas et al., 2011). It has been hypothesized that WM spans tend to require more attentional control than short-term memory spans in the verbal modality, potentially due to the nature of manipulating information while maintaining it in WM (Engle et al., 1999; Hester et al., 2004). In contrast, Miyake et al. (2001) demonstrated that short-term memory and WM tasks in the visuospatial domain are both equally related to executive functioning and heavily implicate controlled attention.

A possible explanation for the discrepancy between the degree of input of attentional control in WM tasks in the verbal and visuospatial domains is that in healthy individuals, verbal (i.e., phonological) information is highly practiced and automatized to a greater degree than visuospatial information. Therefore, visuospatial input may require a greater reliance on executive control mechanisms

than does verbal input. However, we must pose the possibility that for individuals with aphasia, phonological coding that occurs for verbal input may be less automatized than in healthy individuals and consequently may rely more heavily on the central executive system for attentional control related to maintaining a phonological representation. This account would complement Dell's interactive activation model of language production (Dell, 1986), postulating that connection strength among linguistic nodes and decay rate of activated linguistic nodes are two parameters in the language network that work temporally to keep targeted nodes activated to a threshold above competitor nodes. If the lexical retrieval process is impaired—whereby decay rate may be increased and/or connection strength may be decreased—the individual with aphasia may rely more heavily on attentional control to attempt to ignore noise in the system, thereby maintaining activation of a lexical node during the lexical retrieval process. It has been hypothesized that any language impairment that disrupts the ability to maintain active lexical nodes would also affect auditory verbal short-term memory (Martin et al., 1996). Thus, it has been proposed that memory storage and processing are distributed properties of the cognitive system underlying language processing, which may account for deficits that appear to be linguistic in nature, including the ability of nodes to persist in an activated state (Hula & McNeil, 2008; Martin et al., 1996). Of interest in the present study is whether memory processing and storage components related to nonverbal information (such as visuo-perceptual processing) can account for some of the variance in performance on linguistic tasks. Specifically, are those individuals who have better visuospatial nonverbal WM abilities better able to recover from language impairment with treatment? If so, perhaps nonverbal cognitive processes related to WM are also part of the distributed network underlying language processing.

Herein lies the rationale for the present study: If visuospatial abilities are predictive of anomia treatment response, it would support the hypothesis that in individuals with aphasia, there is more central processing of both nonverbal and verbal information. This would support the evolution of WM theories to focus more on central executive mechanisms versus separate verbal and nonverbal modules, initially postulated by Baddeley and Hitch (1974). Recent evidence by Ricker et al. (2010) showed that in healthy individuals, auditory-verbal interference disrupted the storage of visual items held in WM, possibly indicating that visual WM and verbal long-term retrieval are reliant on a central processing mechanism.

From a clinical perspective, the relationship between a cognitive construct (such as nonverbal WM) and response to aphasia treatment may hold prognostic value in predicting those individuals who will best respond to a particular type of treatment or helping to identify who may benefit from WM training prior to beginning anomia treatment. Lambon Ralph, Snell, Fillingham, Conroy, and Sage (2010) examined the relationship between anomia therapy gains and performance on a variety of language and cognitive tasks.

Thirty-three people with aphasia were assessed using tests of naming, reading, repetition, semantic memory and comprehension, attention, visuospatial memory, and executive functioning. After entering the data into a principal component analysis, two principal components were identified: a language factor and a cognitive factor, both of which included verbal and nonverbal tasks of attention and immediate and delayed memory. Further, they found that cognitive and language factors independently predicted anomia therapy gains, but the best predictors were the cognitive factor and the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1983), which was left out of the principal component analysis but highly correlated with the language factor. Hence, consideration of the cognitive abilities of individuals with aphasia may be an important factor in determining how well they will respond to treatment for anomia. To determine the utility of nonverbal WM tasks as a potential predictor of responsiveness to anomia therapy, it will be necessary to first assess the reliability of WM tasks in individuals with aphasia (Mayer & Murray, 2012) because of the potential for high variability in performance across sessions, or day-to-day variability, in this population.

### *Purpose*

The purpose of the study was threefold: In Experiment 1, we aimed to identify the extent to which nonverbal WM performance as measured by the forward and backward conditions of the spatial span (Wechsler, 1997) was reliable across multiple testing sessions in individuals with aphasia. We also aimed to determine whether performance on the spatial span changed after beginning Cued Picture Naming Treatment (CPNT), which may indicate the influence of language abilities or the anomia treatment on span performance. Because anomia treatment was not designed to influence specific cognitive processing associated with memory, we predicted that CPNT would not have a significant effect on either condition of the spatial span. The aim for Experiment 2 was to determine the degree to which nonverbal WM, as measured by the spatial span forward and backward, predicted response to anomia treatment in individuals with chronic aphasia. Evaluated together, these aims should give us a better picture of nonverbal WM performance in individuals with aphasia and determine whether a relationship exists between nonverbal WM and the ability to respond to anomia treatment. If nonverbal visuospatial abilities are predictive of anomia treatment response, then it would be plausible to consider that there are shared processing demands between verbal and visuospatial information in individuals with aphasia. This may be in contrast to individuals without language impairment who show greater demands on attentional control during visuospatial span tasks than they do during verbal span tasks, perhaps because of the automaticity of the phonological code in a healthy language system (Baddeley, 1996; Miyake et al., 2001). Without this automaticity of the phonological code in individuals with aphasia, one may hypothesize that



greater demands are placed on attentional control to complete verbal as well as visuospatial tasks.

## Method

### Participants

The study was approved by the local institutional review board before enrolling participants. Participants were 6 or more months poststroke and had significant anomia as indicated by a raw score of less than 46 but greater than 3 on the BNT (Kaplan et al., 1983). They demonstrated at least minimally intact auditory-verbal comprehension by achieving a score of no less than 2 *SD* below norms on the Auditory Verbal section of the Western Aphasia Battery (WAB; Kertesz, 1982). On the basis of medical records and an interview of the participants and a close family member, they must not have been suspected of having diffuse injury or disease of the brain. They were premorbidly right-handed, as ascertained through administration of the Edinburgh Handedness Inventory (Oldfield, 1971), and they were native English speakers. Participants had no history of drug or alcohol abuse, major affective disorder, or schizophrenia. Participants had no history of diagnosed learning disability, developmental language delays, or attention deficit disorder. Individuals were excluded if they had severe verbal apraxia as determined by a brief examination of apraxia of speech (McNeil, Robin, & Schmidt, 1997).

Eighteen potential participants were recruited for a larger fMRI study. Nine individuals met the inclusion criteria, and eight (two men, six women) completed the present study (Table 1). The study was conducted at two sites with one ASHA-certified speech-language pathologist (SLP) at each site. Each participant received all language therapy from the same SLP.

### WM Assessment Measure

Nonverbal WM abilities were assessed using the Spatial Span subtest of the Wechsler Memory Scales. Experiment 1 aimed to identify the extent to which nonverbal WM performance, as measured by the forward and

backward conditions of the spatial span (Wechsler, 1997), was reliable across multiple testing sessions in individuals with aphasia. We administered the spatial span to individuals with aphasia on 21–25 occasions over a period of 4 weeks. Participants concurrently participated in Experiment 2. They completed both conditions of the spatial span one time on each day of CPNT treatment (for Experiment 2) and up to four times on baseline assessment days, with breaks and alternating tasks (i.e., picture naming) between administrations.

Administration and scoring occurred according to the spatial span protocol. Participants were asked to touch a series of blocks in the same order as the therapist (forward condition) and the reverse order of the therapist (backward condition). Both spatial span order conditions began with touching a series of two blocks (i.e., Level 2). There were two unique trials in each level. If the participant performed at least one of the two trials correctly in Level 2, then the number of blocks advanced to three (i.e., Level 3). Trials continued until the participant made errors on both trials of a level. No participants reached ceiling by completing up to Level 9 on each order condition. All correct trials were given a score of 1, and incorrect trials were given a score of 0. Although clinically the forward and backward spatial span scores are traditionally summed for a total score, for the purposes of this study, we maintained separate scores so that we could investigate potential differences between the processes involved in each task.

### Aphasia Therapy Program

The aphasia therapy used in this research was CPNT (Harnish et al., 2014), modified from Kendall et al. (2014), delivered approximately 1 hr per day, 4 days per week for 2 weeks. The CPNT was described in detail in Harnish et al. (2014). In summary, during treatment, the participant was shown pictures on a computer screen and was asked to name the item after given a series of cues (e.g., repetition, semantic, phonemic, orthographic). Regardless of the correctness of the response, the participant then saw the same picture on seven subsequent trials, each presented with a different cue. If the participant was unable to give a response

**Table 1.** Participant demographics, assessment, CPNT effect size, and first trial spatial span scores.

Participant	Gender	Age	Education in years	Years post CVA	BNT	WAB AQ	WAB classification	CPNT effect size	Span forward 1 <sup>st</sup> trial	Span backward 1 <sup>st</sup> trial
s01	M	47	15	2	4	46.5	Wernicke's	11.75	6	8
s02	F	65	18	3	11	55	Conduction	9.86	9	8
s03	F	45	14	7	23	52	Broca's	6.63	6	6
s04	F	80	14	2	43	80.7	Anomic	11.2	7	7
s05	M	61	15	11	10	43.5	Wernicke's	5.33	9	6
s06	F	52	12	5	39	84.4	Anomic	5	7	2
s07	F	37	16	2	4	35.5	Broca's	4.75	3	2
s08	F	65	18	3	33	74	Transcortical motor	4.29	3	3

Note. CVA = cerebrovascular accident; BNT = Boston Naming Test; WAB AQ = Western Aphasia Battery Aphasia Quotient; CPNT = cued picture naming treatment.

or gave an incorrect label, the therapist then produced the correct label and asked the participant to attempt a repetition. Hence, an opportunity was provided to repeat the word on every trial, even if the picture or cue did not elicit a correct response.

### Procedure

The participants were assessed on picture naming probe items prior to beginning treatment in order to demonstrate stability of naming performance. Probes were delivered at least nine times or until the C statistic (Tryon, 1982) indicated stability. Picture naming probes were delivered throughout CPNT, prior to the treatment session each day, and four times following completion of CPNT. Picture naming probe items were delivered on the computer and scored as correct or incorrect by the treating therapist. A list of potentially acceptable synonyms was created and discussed with the research team until consensus was reached. Participant responses that were different from the target were cross-checked against the list of acceptable responses. Credit was given for acceptable synonyms. Reliability was calculated on 15% of items by the treating therapist and by a therapist unaffiliated with the study. Intrarater reliability was 98.6%, and interrater reliability was 98%. Discrepancies between interrater reliability were settled via discussion.

The forward and backward conditions of the spatial span were delivered prior to each probe session for a larger study. Thus, the same number of picture naming probe sessions and spatial span sessions were conducted during baseline, treatment, and posttreatment. The treating therapist delivered and scored the spatial span online. The spatial span was not recorded; therefore, intra- and interrater reliability was not calculated.

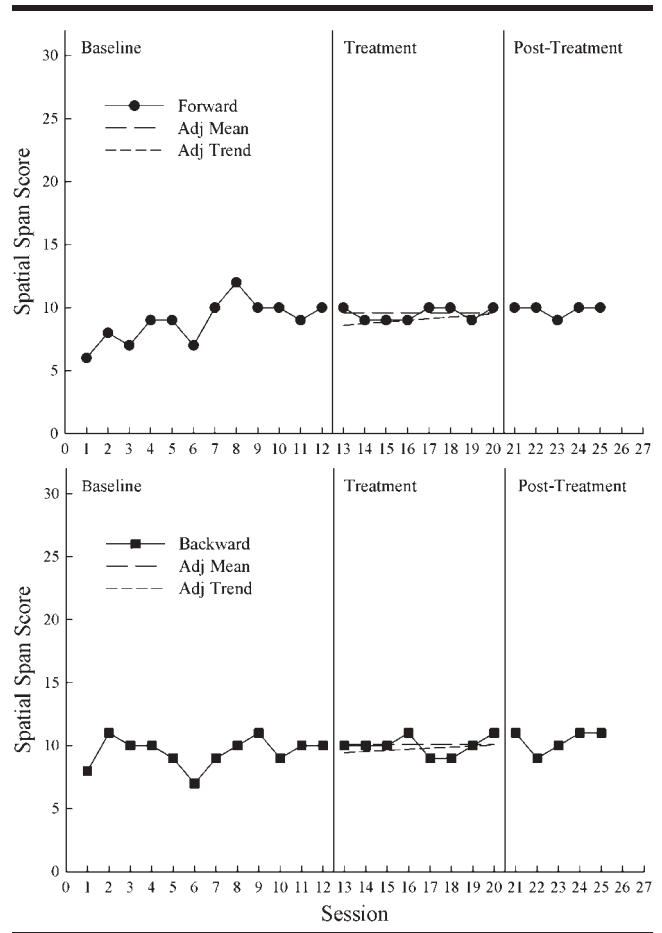
## Experiment 1

### Results

To investigate test-retest reliability of the forward and backward spatial span, Tryon's C statistic (Tryon, 1982) was calculated for all sessions for each participant. Results showed that seven of the eight participants demonstrated stability across all 21–25 sessions ( $p = .05$ ) on the forward condition. Participant s01 did not show stability on the forward spatial span. Five of the eight participants demonstrated stability on the backward condition. Participants s02, s06, and s08 did not show stability on the backward spatial span. See Appendix for raw data on forward and backward conditions for all participants.

To determine whether CPNT affected performance on the spatial span, scores for each participant were plotted across the aphasia treatment baseline, treatment, and post-treatment phases (Figures 1, 2, 3, 4, 5, 6, 7 and 8). The baseline phase was considered stable if there was no ascending or descending trend for at least three probes prior to initiation of treatment. Because these data were a secondary analysis from a larger study, we did not target stability of the spatial

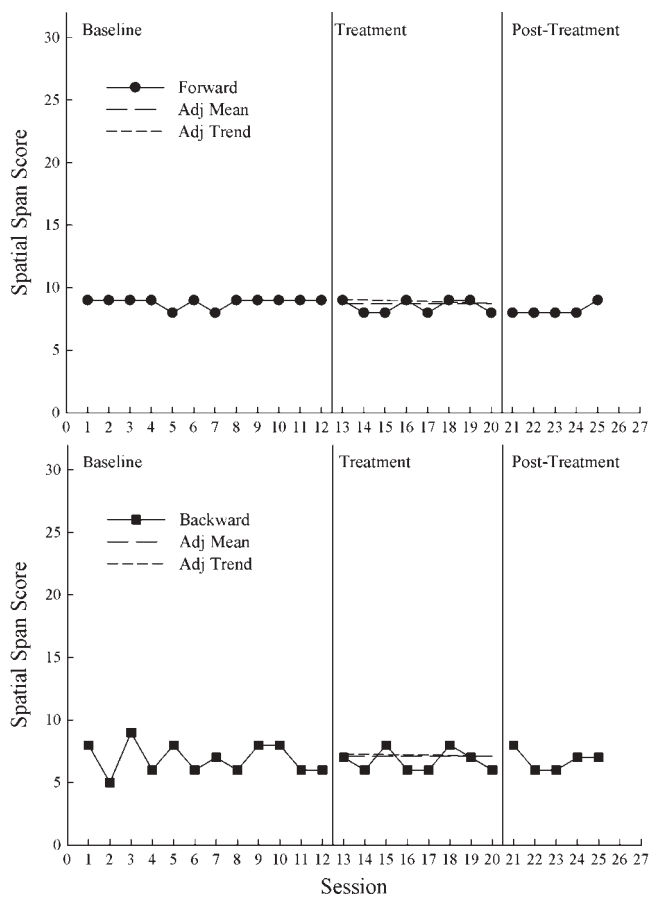
**Figure 1.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s01. Adj = adjusted.



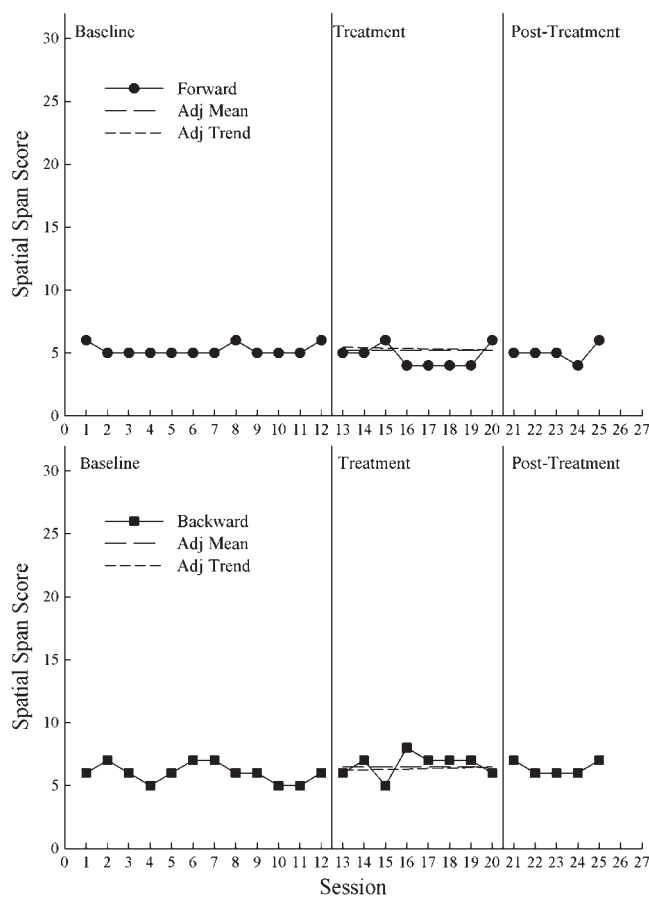
span; however, we retroactively examined whether stability was achieved. Seven of eight participants achieved a stable baseline for forward scores prior to beginning CPNT treatment. All eight participants achieved a stable baseline for backward scores prior to beginning CPNT treatment. Participant s05 showed an ascending trend for the three consecutive spatial span backward scores prior to beginning the anomia treatment phase.

The conservative dual criterion (CDC) method (Fisher, Kelley, & Lomas, 2003) was used to determine whether there were significant increases in the spatial span during the CPNT treatment phase. A mean line was created using the baseline probe data and extended across the treatment phase graph. A trend line was created by determining the least squares linear regression line, based on the baseline intercept and slope. The mean and trend lines were then adjusted in the direction of predicted treatment effect by  $0.25 SD$  as a "reasonable compromise between Type I and Type II errors" (Fisher et al., 2003, p. 387). Each participant's data sets for the forward and backward conditions were evaluated for criterion set in the CDC method for minimum number of data points (e.g., 7 points in this study) above the mean and

**Figure 2.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s02.



**Figure 3.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s03.



trend lines to indicate an upward trend or lack thereof, providing a measure of stability. Results showed that no participants demonstrated significant increases in either condition of the spatial span after beginning CPNT.

## Discussion

Performance on the forward condition of the spatial span remained consistent for seven of the eight participants across all testing sessions. Performance on the backward condition remained consistent for five of the eight participants across all testing sessions. Three participants showed changes that may be related to day-to-day variability in the baseline phase without an upward or downward trend (e.g., s02) or potential practice effects (e.g., s06, s08). These data indicate that the spatial span may be reliable in some individuals but may not be reliable across many testing sessions in all individuals with aphasia, due to the potential of practice effects. However, given the heterogeneity of our population in terms of aphasia type, this task holds promise for measurement of nonverbal visuospatial WM for individuals with varying aphasia syndromes.

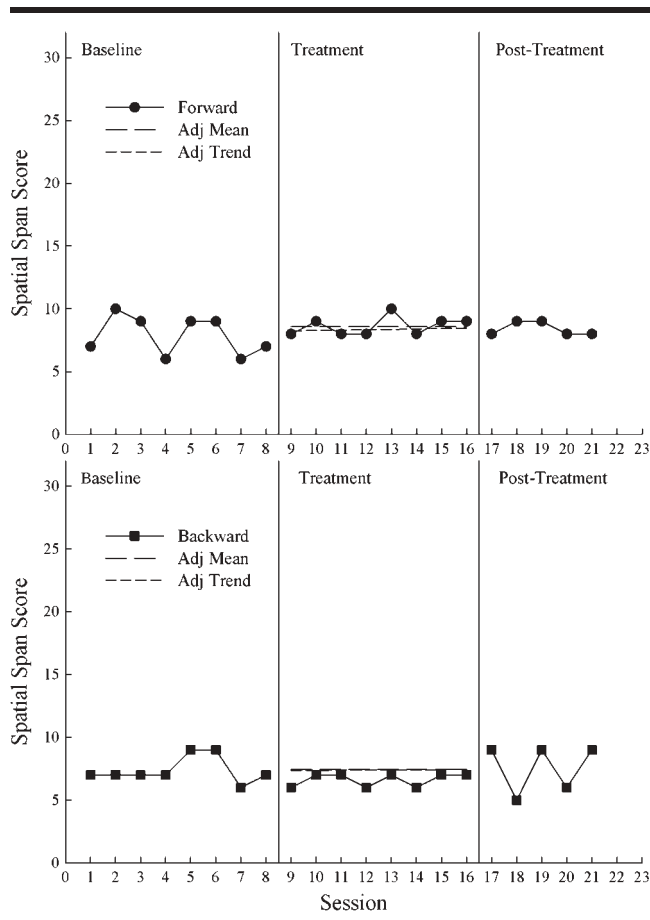
After beginning CPNT, no participants demonstrated significant changes in forward or backward scores, as indicated by the lack of the required number of data points above the CDC mean and trend lines, despite demonstrated changes on naming of trained items during CPNT (see Table 1 for effect sizes). The data also suggest that although CPNT improved lexical retrieval, as expected, it did not rehabilitate processes underlying nonverbal visuospatial WM.

## Experiment 2

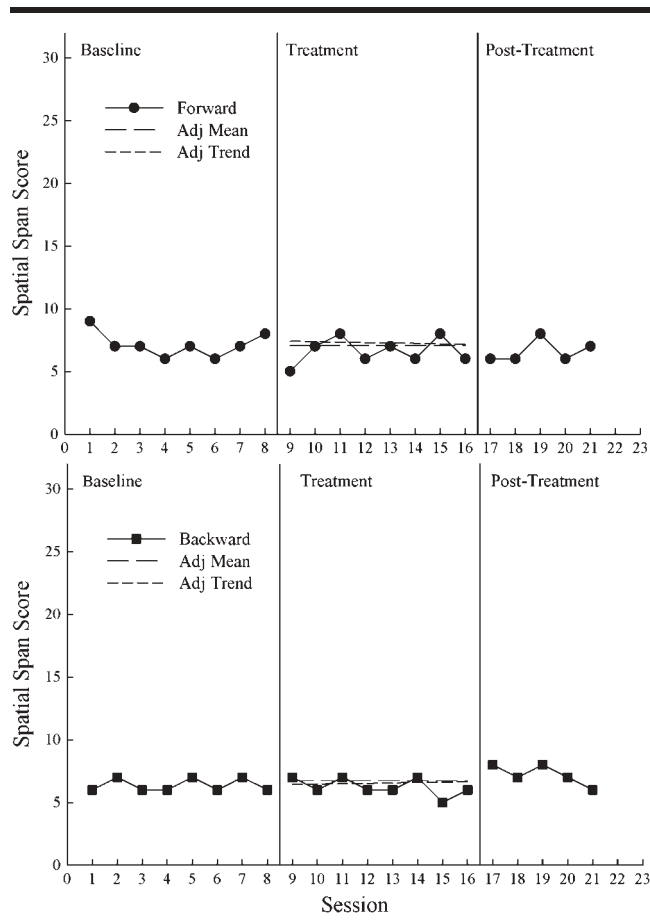
### Results

An analysis of assumptions for multiple regression revealed that assumptions were satisfied for independence of residuals, linearity, homoscedasticity, normality, and multicollinearity. Forward and backward conditions of the spatial span showed a correlation of .617, which is satisfactory for decisions regarding multicollinearity (Stevens, 2002). Tolerance statistics were also satisfactory (forward = 0.619, backward = 1.0; Stevens, 2002). A stepwise multiple

**Figure 4.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s04.



**Figure 5.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s05.



regression analysis was run to evaluate whether forward or backward conditions predicted effect size during CPNT. We used the initial trial of the forward condition and the initial trial of the backward condition as regressors. Effect size was defined as the difference between the mean of all baseline naming probes and the mean of all post-treatment naming probes, divided by the standard deviation of baseline naming probes (Robey & Beeson, 2005). Initial trials and CPNT effect sizes are presented in Table 1. At Step 1 of the analysis, the backward spatial span entered into the regression equation,  $F(1, 6) = 15.202, p = .008$ . The multiple correlation coefficient was .847, and  $R^2$  indicates that approximately 72% of the variance of the effect size could be accounted for by the backward condition. The adjusted  $R^2$  was .670. The forward condition did not enter into the equation at Step 2 of the analysis,  $t = -0.693, p = .519$ . The 95% confidence interval of the spatial span backward was between 0.382 and 1.669. Thus, the regression equation for predicting the effect size of CPNT was: predicted effect size =  $(1.025 \times \text{spatial span backward}) + 1.968$ .

A post hoc Pearson's product-moment correlation was run to assess the relationship between severity of aphasia,

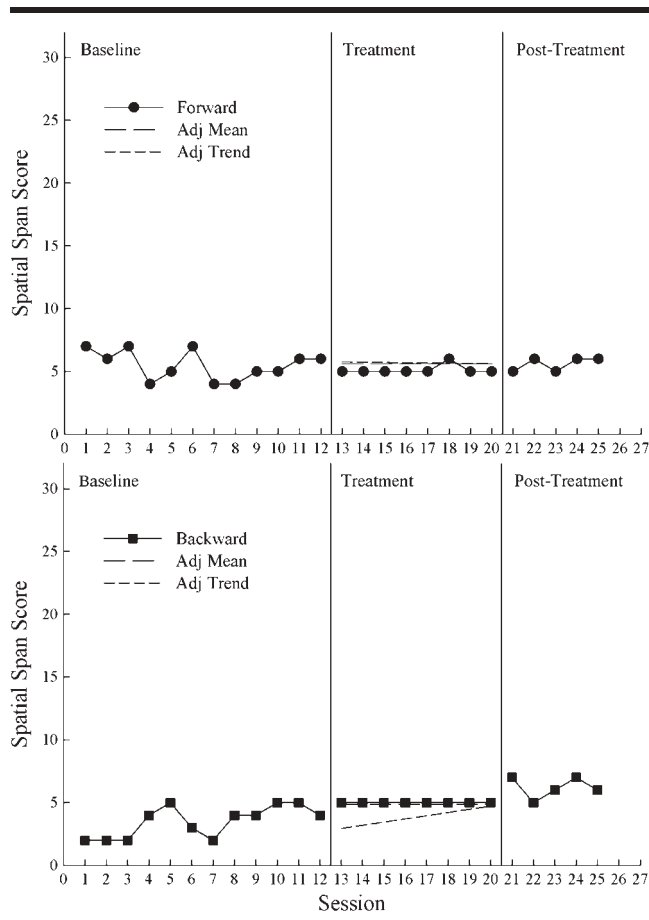
spatial span forward, spatial span backward, and effect size. Preliminary analysis showed the relationships to be linear with all variables normally distributed, as assessed by the Shapiro-Wilk test ( $p > .05$ ). There was a large positive correlation (Cohen, 1988) between the backward condition and effect size,  $r = .847, p = .008$ . No significant correlation was identified between the forward condition and effect size,  $r = .399, p = .328$ ; WAB Aphasia Quotient (AQ) and effect size,  $r = .024, p = .955$ ; BNT and effect size,  $r = -.023, p = .957$ ; backward condition and WAB AQ,  $r = -.200, p = .635$ , nor between the backward condition and BNT,  $r = -.155, p = .714$ . Pearson correlations for these additional study variables are found in Table 2.

### Discussion

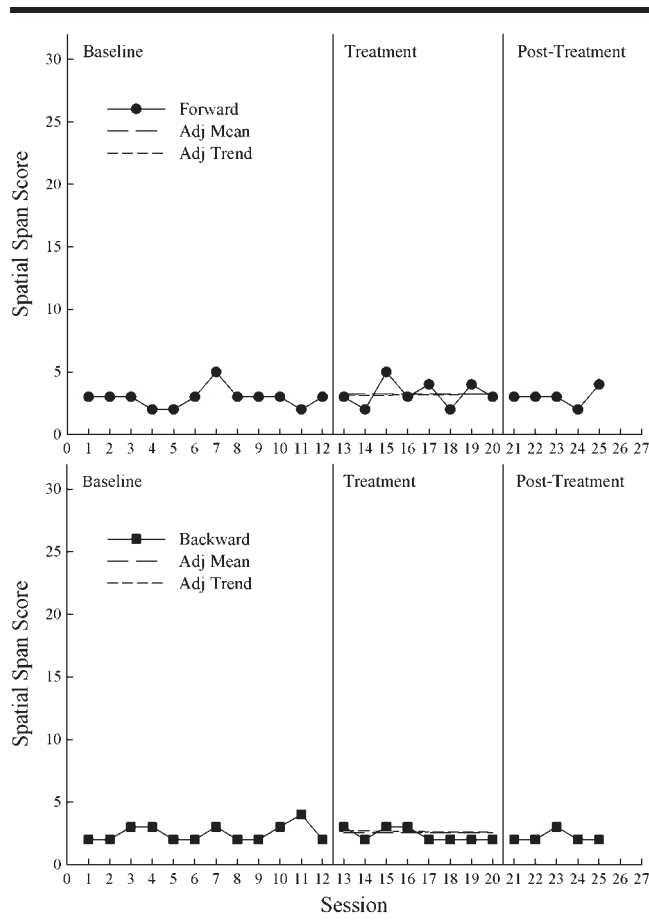
The spatial span backward score for each participant accounted for 72% of the variance in effect sizes demonstrated by our participants after undergoing 2 weeks of treatment for anomia. The forward condition did not significantly contribute to the regression model, indicating that the backward condition was a better predictor of anomia



**Figure 6.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s06.



**Figure 7.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s07.



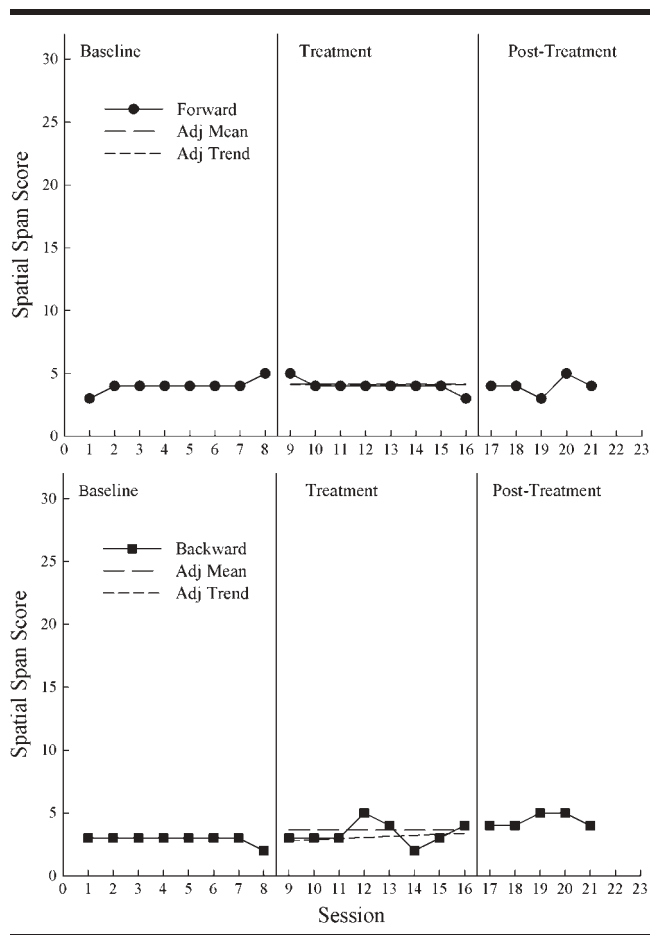
treatment effect size. With the limited sample in this study, the strong trend indicates that (a) there may be a common underlying mechanism supporting both visuospatial memory and the ability to respond to anomia treatment, and (b) nonverbal visuospatial WM may be a good predictor of how well a person will respond to the CPNT treatment. These data are in line with previous data acquired during the acute stages of aphasia rehabilitation (Seniow et al., 2009) showing that baseline nonverbal visuospatial WM, as demonstrated by the Benton Visual Retention Test (Sivan, 1992), was significantly correlated with improvement in naming and comprehension after therapy.

These data are important for at least two main reasons: one theoretical and one clinical. First, it has been heavily debated in the literature whether nonverbal and verbal WM are modulated by (or are part of) the same central mechanism (Brownsett et al., 2014; Cowan, 1988; Cowan et al., 2014; Ricker et al., 2010) or if they are peripherally controlled and processed in separate modules (Baddeley & Hitch, 1974; Shah & Miyake, 1996). Our data support the hypothesis that there is a common underlying mechanism related to both visuospatial WM and improvement in lexical

retrieval after undergoing treatment for anomia using CPNT—that is, the strong relationship between a visuospatial task and response to a verbal treatment indicate that there may be some shared underlying mechanism, especially because other variables may have accounted for this effect. The variables include baseline naming abilities (i.e., BNT) or overall aphasia severity (i.e., WAB AQ), which did not show a relationship with CPNT effect size.

Second, the assessment of spatial memory may serve as a prognostic indicator of which individuals may best respond to particular types of anomia treatment in the acute and chronic stages of aphasia recovery. These findings are consistent with findings from a prior study that showed a similar relationship between visuospatial WM abilities and anomia treatment response (Seniow et al., 2009). If this relationship is replicated in future studies—potentially with other nonverbal visuospatial tasks and other types of anomia treatment—we may be able to clinically develop nonverbal assessment tools related to WM to assist in making treatment decisions. Moreover, with greater elucidation of the mechanism by which this association exists, treatments

**Figure 8.** Forward and backward conditions of the spatial span during baseline, treatment, and posttreatment phases with conservative dual criterion lines for s08.



may be developed to assist with the potential underlying central deficits in tandem with anomia treatment to attempt to maximize treatment response.

## General Discussion

Results of the regression analysis indicated that backward condition of the spatial span was a good predictor of CPNT anomia treatment effect size, but the forward condition did not significantly add to the model. From

a theoretical standpoint, it has been debated whether the forward spatial span engages WM or only short-term memory. Short-term memory spans have been considered simple spans that require temporary storage and retrieval without any additional processing load, whereas WM spans require temporary storage and concurrent processing to manipulate the items prior to output (Cowan, 2008; Hester et al., 2004; Kessels et al., 2008; Potagas et al., 2011). The spatial span forward has been proposed as a simple span measuring short-term retrieval because items are held in memory without manipulating them, whereas the backward condition has been considered a measure of nonverbal WM because the items are held in memory while reversing the order (Hester et al., 2004). We hypothesized that the backward condition would predict the magnitude of CPNT treatment gains because it would better reflect processes underlying nonverbal WM (potentially requiring additional attentional control to complete the task), whereas the forward condition, as a simpler span task, may not have tapped into central processing mechanisms.

The data presented herein indicate that visuospatial WM abilities may be associated with the ability to recover from aphasia with therapy. The following discussion will outline several potential explanations for this finding. The first hypothesis is that intact visuospatial WM may be a prerequisite to using strategies in therapy that help rehabilitate language. The executive control system has been shown to be affected in some individuals with aphasia, as demonstrated by deficits in attention (Caspari et al., 1998; Hula & McNeil, 2008; Murray, 1999, 2012a). Impairment to the executive control system may produce both verbal and nonverbal WM deficits. These deficits may affect the ability to maintain attentional control and organization of input (Lange, Waked, Kirshblum, & DeLuca, 2000) for implementing strategies required for rebuilding lexical connections. It is possible that in the case of more severe nonverbal WM impairment, the system would increasingly rely on available attentional resources within the executive control system. Attentional resources would also likely be taxed during CPNT specifically, because the individual may attempt to maintain a cue in verbal WM while searching for a lexical item.

According to Baddeley and Hitch's (1974) WM model, an impaired executive control system may affect WM in different modalities (i.e., both the visuospatial

**Table 2.** Pearson correlations for additional study variables.

Variable	Span forward	Span backward	CPNT effect size	WAB AQ
Span backward	.617			
CPNT effect size	.399	.847*		
WAB AQ	.045	-.200	.024	
BNT	-.044	-.155	-.023	.907*

*Note.* Span forward and span backward are conditions of the Spatial Span subtest of the Wechsler Memory Scale. CPNT = cued picture naming test; WAB AQ = Western Aphasia Battery Aphasia Quotient; BNT = Boston Naming Test.

\* $p < .05$ .

sketchpad and the phonological loop). Similar relationships could exist with Cowan's model (1988). For example, disruptions both in visual WM and phonological WM may be plausible if a person with aphasia experiences difficulty encoding information due to impaired executive control skills, such as attention (e.g., focus on the target and inhibition of competing information), organization (maintenance and manipulation of information), allocation of resources, or ability to switch strategies when necessary. Thus, nonverbal WM abilities may be associated with anomia treatment gains because both nonverbal WM and verbal WM are dependent upon an intact executive control system. Our finding that nonverbal WM was highly predictive of anomia treatment effect size may be a result of impaired executive control or could indicate that there is some shared central mechanism that accounts for this relationship, such as proposed in Cowan's model (1988) or Baddeley's episodic buffer (2000).

The anomia treatment in the present study requires that the participant see the picture stimuli and respond to the cues provided by the therapist. If the lexical retrieval process fails and the individual is not able to independently retrieve the word on the first presentation, then the participant is given the opportunity to utilize multiple cues to generate a response. Each cue prompts different psycholinguistic processes by which access to the stored representation may be accomplished (e.g., reading the word, hearing the first phoneme, listening to semantic cues about the item). Further, the clinician produces the stimulus correctly if the individual is unable to do so, providing an opportunity for correct encoding into verbal WM. Of importance to the present study is that verbal WM may play a part in the ability to maintain a cue while "searching" for a target word or may maintain the target word while hearing a new cue for that word. Reliance on central attentional processes would also seem plausible. In the CPNT paradigm for this study, there were eight consecutive trials for each of the target words. If there was difficulty encoding the correct word because of difficulties in verbal WM, the participant may not have been able to retrieve it in successive trials, despite the variety of psycholinguistic cues. The ability to use cues in therapy, potentially via a central control process, may have accounted for the relationship with visuospatial processing in the present study.

A second hypothesis for why nonverbal WM abilities may be associated with response to anomia treatment is that the backward condition of the spatial span and CPNT both rely on cognitive processes that are housed in overlapping and damaged brain regions. There is some evidence that the left hemisphere is dominant for processing or storing of successive stimuli that is independent of modality (Baldo & Dronkers, 2006; Chein, Ravizza, & Fiez, 2003). Therefore, left hemisphere lesions may produce a deficit in performance on the backward spatial span because of the task's successive nature, despite the fact that spatial memory is thought to be housed in the right hemisphere. It is unclear whether a deficit in processing or storing successive stimuli may be related to the ability of our participants to

respond to CPNT. During treatment, cues are provided in a sequential manner. Thus, it is possible that someone with intact processing of successive stimuli may be better able to integrate multiple, sequential cues in CPNT and may also perform better on the spatial span.

Finally, although the spatial span is considered a nonverbal assessment of WM, it has been speculated that participants may use a verbal strategy to complete the task. Baldo and Dronkers (2006) suggested that covert verbal strategies may be used during span tasks when the spatial locations are fixed across trials (e.g., middle right, bottom left). One may predict that use of verbal strategies during spatial span tasks—especially helpful with fixed spatial locations as span length increases—can assist with "talking through" the sequence. If spatial memory tasks rely on verbal strategies, then the more severe the language impairment, the worse someone may perform on the task, as a function of severity of aphasia and not WM per se. Potagas et al. (2011) found that there was a relationship between severity of aphasia and performance on memory tasks. Their study compared the performance of a group of individuals with aphasia on digit span ( $n = 44$ ) and spatial span ( $n = 54$ ) and found that aphasia severity, as determined by adjusted scores on Boston Diagnostic Aphasia Examination (Goodglass, Kaplan, & Barresi, 2001) subtests for fluency and comprehension, was significantly correlated with performance on both tasks, indicating that WM and short-term memory tasks in both the verbal and nonverbal modalities were related to the severity of aphasia. In the present study, a post hoc Pearson correlation of our data showed no significant relationship between the mean spatial span total scores and severity of aphasia, as measured by the WAB AQ,  $r(8) = -.016, p = .971$ , or degree of naming deficit, as measured by the BNT,  $r(8) = -.101, p = .811$ . The lack of correlation between severity of aphasia and nonverbal WM in our data may suggest that the ability to use verbal strategies on the spatial span is not the most likely factor underlying the relationship between nonverbal WM abilities and response to aphasia treatment. Additional research is warranted to investigate this relationship.

An interesting caveat related to the possible use of a verbal strategy during the spatial span is that it has been shown that dysarthric patients—unable to articulate—show evidence of subvocal rehearsal (Baddeley & Wilson, 1985); however, dyspraxic patients who have impairment assembling speech—motor control programs do not show evidence of subvocal rehearsal (Caplan & Waters, 1995). Therefore, setting up speech—motor programs to rehearse subvocally may be necessary to maximize response to the CPNT treatment, as well as the spatial span. If this is true, degree of verbal apraxia may be an important factor in performance on both tasks. The present study excluded participants with severe verbal apraxia as determined by a brief examination of apraxia of speech (McNeil et al., 1997), but those with less than severe verbal apraxia were not characterized by degree in order to investigate this link. Future research may examine whether (a) individuals with aphasia utilize a

verbal strategy or subvocal rehearsal to complete the spatial span, and (b) individuals with more severe apraxia of speech demonstrate more difficulty with subvocal rehearsal, potentially contributing to increased difficulty on both the spatial span and response to anomia treatment.

Use of verbal strategies during the spatial span could be covert or overt, such as subvocal rehearsal. Although there were no observations in the present study of any participant using an obvious overt verbal strategy (e.g., left block, behind, up front, beside, etc.), subvocal or covert verbal strategies may have been used. Recent data suggest that inner language may be used for scaffolding high-order cognitive functions, such as mental arithmetic, and may be relied upon to a greater degree for individuals who are less proficient in the cognitive task at hand (Klessinger, Szczerbinski, & Varley, 2012). Covert or inner language shares some brain regions involved in the dorsal route for language—such as the left pars opercularis, left supramarginal gyrus, and white matter near the supramarginal gyrus—suggesting that inner language is processed in Broca's area and travels via the arcuate fasciculus to posterior regions that integrate production and comprehension (Geva et al., 2011). The participants with aphasia in the present study may have experienced deficits in organizing inner language to assist with both the spatial span and using cues in the anomia treatment to facilitate language recovery.

It is unclear whether WM impairments in individuals with aphasia are due to difficulty with encoding, consolidation, storage, or retrieval. There are some data to suggest that visual memory impairment in both left and right hemisphere stroke is a result of deficient encoding of information resulting from impaired organizational skills (Lange et al., 2000). Future studies should investigate whether recall of material is significantly influenced by the quality of the organizational strategies used during initial encoding. If so, it may be worthwhile to train organizational strategies concurrently with treatment for anomia.

### Limitations

The findings from this study are limited due to the small sample size. Although these data showed a strong trend for the backward spatial span to predict response to CPNT, we caution that the findings should be replicated in a larger sample. Due to the strong correlation between a measure of visuospatial WM and response to anomia treatment in the present study—consistent with similar findings from Seniow et al. (2009)—we feel that future research is warranted, both to replicate the current findings and further elucidate the mechanism by which these two processes may interact.

It is possible that practice effects occurred as a result of repeated presentation of the spatial span sequences. The spatial span uses the same sequences for the forward and backward conditions. It has been argued that this may facilitate implicit learning (Milner, 1971), similar to 32% of participants in a retrospective study of a mixed clinical population (Wilde & Strauss, 2002), who demonstrated

more correct trials on the backward condition than on the forward condition. However, the same pattern did not occur on the digit span, which does not replicate sequences for the forward and backward conditions. In the present study, only one participant (s03) performed slightly better on the backward condition and did so regularly; however, of greater importance in the present study is the repeated presentation of the sequence across multiple testing sessions. The backward condition always occurred after the forward condition, which may have contributed to implicit learning. Further, three of the participants did not show stability in the backward condition, based on Tyron's C statistic, which could have potentially been related to practice effects.

Another limitation of this study is that a single measure of visuospatial WM was used as the independent variable, as opposed to a battery of nonverbal WM assessments. Waters and Caplan (2003) suggested that a composite score of two or three WM tasks—such as alphabet span, subtract two span, and sentence span—may increase test-retest reliability and reliability in healthy elderly people more than would any of the measures used alone. These data are a secondary analysis of data collected for a larger study. We chose the forward and backward spatial span because they are nonverbal and relatively easy to administer to individuals with aphasia. Many studies on individuals with aphasia have used span tasks to assess nonverbal WM (Burgio & Basso, 1997; De Renzi & Nichelli, 1975; Potagas et al., 2011), although other figure recognition paradigms have been used (Kalbe, Reinhold, Brand, Markowitsch, & Kessler, 2005). The addition of other measures into a battery of nonverbal WM would strengthen reliability in future studies.

### Conclusions

It is well known that individuals with aphasia often experience comorbid cognitive deficits, including impairment in verbal and nonverbal WM (Caspari et al., 1998; Hula & McNeil, 2008; Murray, 1999, 2012a). In one prior study, it was shown that visuospatial WM abilities are associated with improvement in therapy during the acute phases of aphasia recovery (Seniow et al., 2009). The present study has demonstrated that in eight individuals with chronic aphasia, nonverbal visuospatial WM abilities (as seen in performance on the backward spatial span) were highly predictive of response to an anomia treatment, CPNT. As expected, no significant changes in forward or backward conditions of the spatial span performance occurred after beginning CPNT, indicating that CPNT likely does not affect visuospatial WM abilities.

If a central processing mechanism, such as Baddeley's (2000) central executive (e.g., attentional control, allocation of resources, manipulation of information, or switching strategies) or episodic buffer (e.g., chunking and storage of information) is indeed heavily relied upon for individuals with aphasia in both visuospatial and auditory-verbal WM, then the fact that the backward spatial span did not



significantly change for five of eight of our participants means that, at least for these five participants, central processes were likely not altered via our treatment. This would be expected, as the treatment did not explicitly target attention or other executive processes. We agree with Hula and McNeil (2008) and Martin, Kohen, Kalinyak-Fliszar, Soveri, and Laine (2012), who suggested that if cognitive abilities (such as controlled attention and short-term memory) are responsible for or contribute to language disturbances, then they should be targeted in the context of the language functions to be rehabilitated.

Because the backward spatial span was a strong predictor of anomia treatment outcomes, we believe that future research is warranted to replicate the findings in studies using other anomia treatment paradigms and visuospatial WM tasks, seeking to determine whether this effect is task or treatment specific. Data from Seniow et al. (2009) also demonstrated this relationship between visuospatial WM and improvements in naming and comprehension using the Benton Visual Retention Test (Sivan, 1992). Moreover, a battery of nonverbal WM assessments, including attention measures, would help determine whether a shared processing mechanism (and which mechanism specifically) may be responsible. Although we did not assess verbal WM in the present study, candidate tasks that do not require verbal responses for individuals with aphasia—such as matching listening span (Salis, 2012) and pointing span (Dede, Ricca, Knilans, & Trubl, 2014)—may prove fruitful in advancing this line of research.

Additional research should investigate whether training visuospatial memory or organizational strategies prior to initiation of anomia treatment would provide a stronger WM foundation on which to begin rehabilitation of language. There is limited evidence that WM treatments may be effective in people with aphasia in terms of improving memory as well as language outcomes (see Murray, 2012b, for a review). Assessment of nonverbal WM abilities may also prove to be valuable in determining those patients who may be most suited to begin CPNT or other similar anomia treatments or in identifying those patients who may benefit from additional cognitive training to allow for maximum therapeutic gains.

In conclusion, the present data demonstrate that visuospatial WM abilities were highly predictive of anomia treatment response in a small sample of individuals with aphasia. The data support an account of memory that includes a central processing mechanism, one that may be taxed to a greater degree for auditory-verbal information in individuals with aphasia due to decreased automaticity of the phonological code.

## References

- Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2002). Individual differences in working memory within a nomological network of cognitive and perceptual speed abilities. *Journal of Experimental Psychology: General, 131*(4), 567–589.
- Anderson, J. S., Ferguson, M. A., Lopez-Larson, M., & Yurgelun-Todd, D. (2010). Topographic maps of multisensory attention. *Proceedings of the National Academy of Sciences, 107*, 20110–20114.
- Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 2, pp. 89–195). New York, NY: Academic Press.
- Baddeley, A. (1996). The fractionation of working memory. *Proceedings of the National Academy of Sciences, 93*, 13468–13472.
- Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417–423.
- Baddeley, A. D. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36*, 189–208.
- Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York, NY: Academic Press.
- Baddeley, A. D., & Wilson, B. A. (1985). Phonological coding and short-term memory in patients without speech. *Journal of Memory and Language, 24*, 490–502.
- Baldo, J. V., & Dronkers, N. F. (2006). The role of inferior parietal and inferior frontal cortex in working memory. *Neuropsychology, 20*, 529–538.
- Brownsett, S. L., Warren, J. E., Geranmayeh, F., Woodhead, Z., Leech, R., & Wise, R. J. (2014). Cognitive control and its impact on recovery from aphasic stroke. *Brain, 137*(Pt. 1), 242–254.
- Burgio, F., & Basso, A. (1997). Memory and aphasia. *Neuropsychologia, 35*, 759–766.
- Caplan, D., & Waters, G. A. (1995). On the nature of the phonological output planning process involved in verbal rehearsal: Evidence from aphasia. *Brain and Language, 48*, 191–220.
- Caspari, I., Parkinson, S. R., LaPointe, L. L., & Katz, R. C. (1998). Working memory and aphasia. *Brain and Cognition, 37*(2), 205–223.
- Chein, J. M., Ravizza, S. M., & Fiez, J. A. (2003). Using neuroimaging to evaluate models of working memory and their applications for language processing. *Journal of Neurolinguistics, 16*, 315–339.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.
- Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. *Psychological Bulletin, 104*(2), 163–191.
- Cowan, N. (1997). *Attention and memory*. Oxford, UK: Oxford University Press.
- Cowan, N. (2008). What are the differences between long-term, short-term, and working memory? *Progress in Brain Research, 169*, 323–388.
- Cowan, N., Fristoe, N. M., Elliott, E. M., Brunner, R. P., & Saults, J. S. (2006). Scope of attention, control of attention, and intelligence in children and adults. *Memory & Cognition, 34*, 1754–1768.
- Cowan, N., Li, D., Moffitt, A., Becker, T. M., Martin, E. A., Saults, J. S., & Christ, S. E. (2011). A neural region of abstract working memory. *Journal of Cognitive Neuroscience, 23*, 2852–2863.
- Cowan, N., Saults, J. S., & Blume, C. L. (2014). Central and peripheral components of working memory storage. *Journal of Experimental Psychology: General, 143*, 1806–1836.
- De Renzi, E., & Nichelli, P. (1975). Verbal and non-verbal short-term memory impairment following hemispheric damage. *Cortex, 11*, 341–354.

- Dede, G., Ricca, M., Knilans, J., & Trubl, B. (2014). Construct validity and reliability of working memory tasks for people with aphasia. *Aphasiology*, 28, 692–712.
- Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, 93(3), 283–321.
- Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, 128, 309–331.
- Fisher, W. W., Kelley, M. E., & Lomas, J. E. (2003). Visual aids and structured criteria for improving visual inspection and interpretation of single-case designs. *Journal of Applied Behavior Analysis*, 36, 387–406.
- Friedman, N. P., & Miyake, A. (2000). Differential roles for visuospatial and verbal working memory in situation model construction. *Journal of Experimental Psychology: General*, 129, 61–83.
- Gernsbacher, M. A. (1993). Less skilled readers have less efficient suppression mechanisms. *Psychological Science*, 4, 294–298.
- Geva, S., Jones, P. S., Crinion, J. T., Price, C. J., Baron, J., & Warburton, E. A. (2011). The neural correlates of inner speech defined by voxel-based lesion-symptom mapping. *Brain*, 134, 3071–3082.
- Glosser, G., & Goodglass, H. (1990). Disorders in executive control functions among aphasic and other brain-damaged patients. *Journal of Clinical and Experimental Neuropsychology*, 12, 485–501.
- Goodglass, H., Kaplan, E., & Barresi, B. (2001). *Boston Diagnostic Aphasia Examination* (3rd ed.). Philadelphia, PA: Lippincott Williams & Wilkins.
- Harnish, S. M., Morgan, J., Lundine, J. P., Bauer, A., Singletary, F., Benjamin, M. L., . . . Crosson, B. (2014). Dosing of a cued picture-naming treatment for anomia. *American Journal of Speech-Language Pathology*, 23, S285–S299.
- Hester, R. L., Kinsella, G. J., & Ong, B. (2004). Effect of age on forward and backward span tasks. *Journal of the International Neuropsychological Society*, 10, 475–481.
- Hitch, G. J., Towse, J. N., & Hutton, U. (2001). What limits children's working memory span? Theoretical accounts and applications for scholastic development. *Journal of Experimental Psychology: General*, 130, 184–198.
- Hula, W., & McNeil, M. R. (2008). Models of attention and dual-task performance as explanatory constructs in aphasia. *Seminars in Speech and Language*, 29(3), 169–187.
- Kalbe, E., Reinhold, N., Brand, M., Markowitsch, H. J., & Kessler, J. (2005). A new test battery to assess aphasic disturbances and associated cognitive dysfunctions – German normative data on the aphasia check list. *Journal of Clinical and Experimental Neuropsychology*, 27, 779–794.
- Kane, M. J., Bleckley, M. K., Conway, A. R., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, 130, 169–183.
- Kaplan, E., Goodglass, H., & Weintraub, S. (1983). *Boston Naming Test*. Philadelphia, PA: Lea & Febiger.
- Kendall, D., Raymer, A., Rose, M., Gilbert, J., & Gonzalez Rothi, L. J. (2014). Anomia treatment platform as behavioral engine for use in research on physiological adjuvants to neurorehabilitation. *Journal of Rehabilitation Research & Development*, 51, 391–400.
- Kertesz, A. (1982). *Western Aphasia Battery*. New York, NY: Grune & Stratton.
- Kessels, R. P., van den Berg, E., Ruis, C., & Brands, A. M. (2008). The backward span of the Corsi Block-Tapping Task and its association with the WAIS-III Digit Span. *Assessment*, 15, 426–434.
- King, J., & Just, M. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, 30, 580–602.
- Klessinger, N., Szczerbinski, M., & Varley, R. (2012). The role of number words: The phonological length effect in multidigit addition. *Memory and Cognition*, 40, 1289–1302.
- Korda, R. J., & Douglas, J. M. (1997). Attention deficits in stroke patients with aphasia. *Journal of Clinical and Experimental Neuropsychology*, 19, 525–542.
- Lambon Ralph, M. A., Snell, C., Fillingham, J. K., Conroy, P., & Sage, K. (2010). Predicting the outcome of anomia therapy for people with aphasia post CVA: Both language and cognitive status are key predictors. *Neuropsychological Rehabilitation*, 20, 289–305.
- Lang, C. J., & Quitz, A. (2012). Verbal and nonverbal memory impairment in aphasia. *Journal of Neurology*, 259, 1655–1661.
- Lange, G., Waked, W., Kirshblum, S., & DeLuca, J. (2000). Organizational strategy influence on visual memory performance after stroke: Cortical/subcortical and left/right hemisphere contrasts. *Archives of Physical Medicine and Rehabilitation*, 81, 89–94.
- Laures-Gore, J., Marshall, R. S., & Verner, E. (2011). Performance of individuals with left-hemisphere stroke and aphasia and individuals with right brain damage on forward and backward digit span tasks. *Aphasiology*, 25, 43–56.
- Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General*, 130, 199–207.
- Majerus, S., Poncelet, M., Van der Linden, M., Albouy, G., Salmon, E., Sterpenich, V., . . . Maquet, P. (2006). The left intraparietal sulcus and verbal short-term memory: Focus of attention or serial order? *NeuroImage*, 32, 880–891.
- Martin, N., Kohen, F., Kalinyak-Fliszar, M., Soveri, A., & Laine, M. (2012). Effects of working memory load on processing of sounds and meanings of words in aphasia. *Aphasiology*, 26, 462–493.
- Martin, N., Saffran, E. M., & Dell, G. S. (1996). Recovery in deep dysphasia: Evidence for a relation between auditory-verbal STM capacity and lexical errors in repetition. *Brain and Language*, 52, 83–113.
- Mayer, J. F., & Murray, L. L. (2012). Measuring working memory deficits in aphasia. *Journal of Communication Disorders*, 45, 325–339.
- McNeil, M. R., Robin, D. A., & Schmidt, R. A. (1997). Apraxia of speech: Definition, differentiation, and treatment. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (pp. 311–344). New York, NY: Thieme.
- Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. *British Medical Bulletin*, 27, 272–277.
- Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology: General*, 130, 621–640.
- Murray, L. L. (1999). Review attention and aphasia: Theory, research and clinical implications. *Aphasiology*, 13, 91–111.
- Murray, L. L. (2012a). Attention and other cognitive deficits in aphasia: Presence and relation to language and communication measures. *American Journal of Speech-Language Pathology*, 21, S51–S64.
- Murray, L. L. (2012b). Direct and indirect treatment approaches for addressing short-term or working memory deficits in aphasia. *Aphasiology*, 26, 317–337.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97–113.

- Potagas, C., Kasselimis, D., & Evdokimidis, I. (2011). Short-term and working memory impairments in aphasia. *Neuropsychologia*, 49, 2874–2878.
- Ricker, T. J., Cowan, N., & Morey, C. C. (2010). Visual working memory is disrupted by covert verbal retrieval. *Psychonomic Bulletin & Review*, 17, 516–521.
- Robey, R. R., & Beeson, P. M. (2005, November). *Aphasia treatment: Examining the evidence*. Paper presented at the American Speech-Language-Hearing Association Annual Convention, San Diego, CA.
- Salis, C. (2012). Short-term memory treatment: Patterns of learning and generalisation to sentence comprehension in a person with aphasia. *Neuropsychological Rehabilitation*, 22, 428–448.
- Seniow, J., Litwin, M., & Lesniak, M. (2009). The relationship between non-linguistic cognitive deficits and language recovery in patients with aphasia. *Journal of the Neurological Sciences*, 283(15), 91–94.
- Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General*, 125, 4–27.
- Sivan, A. B. (1992). *Benton Visual Retention Test* (5th ed.). San Antonio, TX: Psychological Corporation.
- Smyth, M. M., & Scholey, K. A. (1992). Determining spatial span: The role of movement time and articulation rate. *Quarterly Journal of Experimental Psychology*, 45, 479–501.
- Stevens, J. P. (2002). *Applied multivariate statistics for the social sciences* (4th ed.). Mahwah, NJ: Erlbaum.
- Todd, J. J., & Marois, R. (2004, April 15). Capacity limit of visual short-term memory in human posterior parietal cortex. *Nature*, 428, 751–754.
- Tryon, W. W. (1982). A simplified time-series analysis for evaluating treatment interventions. *Journal of Applied Behavior Analysis*, 15, 423–429.
- Vandierendonck, A., Kemps, E., Fastame, M. C., & Szmalec, A. (2004). Working memory components of the Corsi blocks task. *British Journal of Psychology*, 95(Pt. 1), 57–79.
- Villard, S., & Kiran, S. (2015). Between-session intra-individual variability in sustained, selective, and integrational non-linguistic attention in aphasia. *Neuropsychologia*, 66, 204–212.
- Waters, G. S., & Caplan, D. (2003). The reliability and stability of verbal working memory measures. *Behavior Research Methods, Instruments, & Computers*, 35(4), 550–564.
- Wechsler, D. (1997). *WMS-III administration and scoring manual*. San Antonio, TX: The Psychological Corporation, Harcourt Brace Jovanovich.
- Ween, J. E., Verfaellie, M., & Alexander, M. P. (1996). Verbal memory function in mild aphasia. *Neurology*, 47, 795–801.
- Wilde, N. J., & Strauss, E. (2002). Functional equivalence of WAIS-III/WMS-III digit and spatial span under forward and backward recall conditions. *Clinical Neuropsychology*, 16, 322–330.
- Wilde, N. J., Strauss, E., & Tulskey, D. S. (2004). Memory span on the Wechsler Scales. *Journal of Clinical and Experimental Neuropsychology*, 26, 539–549.
- Wright, H. H., & Fergadiotis, G. (2012). Conceptualizing and measuring working memory and its relationship to aphasia. *Aphasiology*, 26, 258–278.
- Xu, Y., & Chun, M. M. (2006, March 2). Dissociable neural mechanisms supporting visual short-term memory for objects. *Nature*, 440, 91–95.

## Appendix

**Table A1.** Spatial span data for each subject in forward (F) and backward (B) conditions.

Trial	S01		S02		S03		S04		S05		S06		S07		S08	
	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B
1	6	8	9	8	6	6	7	7	9	6	7	2	3	2	3	3
2	8	11	9	5	5	7	10	7	7	7	6	2	3	2	4	3
3	7	10	9	9	5	6	9	7	7	6	7	2	3	3	4	3
4	9	10	9	6	5	5	6	7	6	6	4	4	2	3	4	3
5	9	9	8	8	5	6	9	9	7	7	5	5	2	2	4	3
6	7	7	9	6	5	7	9	9	6	6	7	3	3	2	4	3
7	10	9	8	7	5	7	6	6	7	7	4	2	5	3	4	3
8	12	10	9	6	6	6	7	7	8	6	4	4	3	2	5	2
9	10	11	9	8	5	6	8	6	5	7	5	4	3	2	5	3
10	10	9	9	8	5	5	9	7	7	6	5	5	3	3	4	3
11	9	10	9	6	5	5	8	7	8	7	6	5	2	4	4	3
12	10	10	9	6	6	6	8	6	6	6	6	4	3	2	4	5
13	10	10	9	7	5	6	10	7	7	6	5	5	3	3	4	4
14	9	10	8	6	5	7	8	6	6	7	5	5	2	2	4	2
15	9	10	8	8	6	5	9	7	8	5	5	5	5	3	4	3
16	9	11	9	6	4	8	9	7	6	6	5	5	3	3	3	4
17	10	9	8	6	4	7	8	9	6	8	5	5	4	2	4	4
18	10	9	9	8	4	7	9	5	6	7	6	5	2	2	4	4
19	9	10	9	7	4	7	9	9	8	8	5	5	4	2	3	5
20	10	11	8	6	6	6	8	6	6	7	5	5	3	2	5	5
21	10	11	8	8	5	7	8	9	7	6	5	7	3	2	4	4
22	10	9	8	6	5	6					6	5	3	2		
23	9	10	8	6	5	6					5	6	3	3		
24	10	11	8	7	4	6					6	7	2	2		
25	10	11	9	7	6	7					6	6	4	2		