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Remediation of language processing in aphasia: Improving activation and maintenance of linguistic representations in (verbal) short-term memory

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Abstract

Background—Verbal short-term memory (STM) impairments are invariably present in aphasia. Word processing involves a minimal form of verbal STM, i.e., the time course over which semantic and phonological representations are activated and maintained until they are comprehended, produced, or repeated. Thus it is reasonable that impairments of word processing and verbal STM may co-occur. The co-occurrence of language and STM impairments in aphasia has motivated an active area of research that has revealed much about the relationship of these two systems and the effect of their impairment on language function and verbal learning (Freedman & Martin, 2001; Martin & Saffran, 1999; Trojano & Grossi, 1995). In keeping with this view a number of researchers have developed treatment protocols to improve verbal STM in order to improve language function (e.g., Koenig-Bruhin & Studer-Eichenberger, 2007). This account of aphasia predicts that treatment of a fundamental ability, such as STM, which supports language function, should lead to improvements that generalise to content and tasks beyond those implemented in treatment.

Aims—We investigated the efficacy of a treatment for language impairment that targets two language support processes: verbal short-term memory (STM) and executive processing, in the context of a language task (repetition). We hypothesised that treatment of these abilities would improve repetition abilities and performance on other language tasks that require STM.

Method—A single-participant, multiple-baseline, multiple-probe design across behaviours was used with a participant with conduction aphasia. The treatment involved repetition of words and nonwords under three “interval” conditions, which varied the time between hearing and repeating the stimulus. Measures of treatment effects included acquisition, maintenance, and follow-up data, effect sizes, and pre- and post-treatment performance on a test battery that varies the STM and executive function demands of language tasks.

Outcomes & Results—Improvement of repetition was mostly specific to treated stimuli. Post-treatment measures of language ability indicated improvements in single and multiple word processing tasks, verbal working memory tasks, and verbal span.

Conclusions—Treatment of STM and executive processes in the context of a word repetition task resulted in improvements in other non-treated language tasks. The approach used in this study can be incorporated into other language-processing tasks typically used in treatment of language disorders (e.g., sentence processing).

Keywords

Verbal short-term memory; Language processing; Treatment; Aphasia

Our understanding of the nature of language impairment in aphasia has evolved over many years of research. Most aphasiologists subscribe to the idea that aphasia is an impairment of language performance and not language competence. In cognitive terms, aphasia affects the ability to *process* linguistic knowledge (e.g., semantic, phonological, syntactic) and does not reflect a *loss* of that knowledge. Research efforts to determine the nature of the processing deficit in aphasia have focused on cognitive abilities such as short-term memory (Martin, 2008; Martin & Saffran, 1997; R. Martin, Shelton, & Yaffee, 1994; Saffran, 1990) and executive functions (Miyake, Emerson, & Friedman, 2000; Purdy, 2002), which enable linguistic representations to be activated and maintained over the time course for comprehension and production of language. Verbal short-term memory (STM) impairments are pervasive in individuals with aphasia. The co-occurrence of language and STM impairments in aphasia has motivated an active area of research that has revealed much about the relationship of these two systems and the effect of their impairment on language function and verbal learning (Freedman & Martin, 2001; Martin & Saffran, 1999; Trojano & Grossi, 1995). Additionally, some individuals with aphasia demonstrate deficits in executive functions (R. Martin & Allen, 2008) and allocation of attentional resources in language processing (e.g., Hula & McNeil, 2008; Tseng, McNeil, & Milenkovic, 1993). Evidence that “extra-linguistic” cognitive abilities support language function is consistent with the view of aphasia as a disorder of language processing. Implicit in a “processing” model of aphasia is the assumption that treatment of fundamental cognitive abilities that support language function, such as STM and executive functions, should lead to improved language abilities that generalise to content and tasks beyond those used in treatment.

In this case study we tested this hypothesis using a treatment to improve word processing by targeting the ability to access and maintain activation of phonological representations in word and nonword repetition tasks that (1) varied verbal STM memory load and (2) varied verbal STM memory load in the context of verbal competition. Below we briefly review research indicating a role of short-term memory processes in word processing (maintenance of activated linguistic representations) as well as involvement of executive processes in language function, especially in contexts that introduce verbal competition.

EVIDENCE THAT WORD PROCESSING AND VERBAL STM SHARE A COMMON SHORT-TERM ACTIVATION MAINTENANCE PROCESS

Historically, investigations of language processing and verbal STM have proceeded as separate enterprises, even though the content of verbal memory *is* language and the two systems are deployed jointly in all language and verbal learning tasks. Whereas studies of lexical processing (e.g., Dell & O’Searghda, 1992; Levelt, 1992) focused on access and retrieval of single words, studies of verbal STM often minimised the complexity of the verbal content, using digits, letters, or short words in span tasks (e.g., Conrad & Hull, 1964). Theorists recognised that both systems worked together, and their models reflected this to some extent (Baddeley & Hitch, 1974; Craik & Lockhart, 1972). However, the separate investigations of word processing and STM provided the opportunity to determine properties unique to each system.

In recent years interest in the relationship of language and verbal STM has increased. One model that has greatly influenced conceptions of this relationship is Baddeley’s working memory model (Baddeley, 1986; Baddeley & Hitch, 1974). This model assumes that

representations in STM are phonological and are temporary activations of long-term phonological knowledge. Their activation is refreshed by a rehearsal process that accesses long-term semantic and phonological representations. Semantic representations of words are not held in STM but influence maintenance of the contents of verbal STM via the rehearsal process. This model, which assumes language and STM are independent but cooperative systems, provided a theoretical framework of the relationship of language and STM that was invoked by researchers using neuropsychological data to study impairments of language and STM in aphasia (e.g., Warrington & Shallice, 1969).

Another view that emerged during this period was that language and STM systems are linked by a shared fundamental process: activation and maintenance of semantic and phonological representations of words (Berndt & Mitchum, 1990; R. Martin et al., 1994; Saffran, 1990; Saffran & Martin, 1990a, 1990b). Execution of any language task takes place over time. Thus, to process even a single word, some mechanism is needed to maintain activation of that word's representations until its comprehension, production, or repetition is complete. This brief period of maintenance constitutes a minimal form of STM. This view of the relationship of verbal STM and language systems presumes that they are linked by this common ability to maintain activation of semantic and phonological representations of words as they are processed as single units or components of word sequences, phrases, or sentences.

This model is supported by converging evidence from studies of the influence of language processing on verbal STM capacity. It is well documented, for example, that verbal span capacity varies depending on the characteristics of the items to be recalled. Span is greater for digits than words (Brener, 1940) and greater for words than nonwords (Hulme, Maughan, & Brown, 1991). Span capacity is influenced by linguistic factors such as phonological similarity (Conrad & Hull, 1964), word frequency (Hulme et al, 1997; Watkins & Watkins, 1977), and semantic similarity (Brooks & Watkins, 1990; Crowder, 1979; Poirier & Saint Aubin, 1995; Shulman, 1971). Additionally, linguistic influences on verbal span have been demonstrated in studies of verbal STM impairments associated with aphasia. These studies have documented quite dramatic effects of lexical and semantic factors (e.g., frequency and imageability) on item recall in verbal span (Hanley & Kay, 1997; Martin & Saffran, 1997) and serial order (Martin & Bunta, 2007; Martin & Gruberg, 2009; Martin & Saffran, 1997). Evidence from these studies may reflect the interaction of two independent systems. Alternatively, a model that postulates a common cognitive process supporting word processing and verbal STM ("activation maintenance") can account for these findings.

EVIDENCE FOR INVOLVEMENT OF EXECUTIVE FUNCTIONS IN LANGUAGE PROCESSING

In keeping with the overarching hypothesis that language processing is supported by nonlinguistic cognitive processes that support activation, maintenance, and retrieval of linguistic representations, it is reasonable to assume that short-term memory is not the only such support process. There is much recent interest in the role of executive processes in language function that serve to "control" or enable efficiency of processing information in language and other cognitive domains. At the behavioural level they refer to abilities such as planning, sequencing, sustaining attention, inhibiting irrelevant stimuli, coordination of simultaneous ability, and cognitive flexibility (Crawford, 1998). Miyake, Friedman, et al (2000) note three executive functions that are important to the regulation of language processing: mental shifting, inhibition, and working memory updating and monitoring. Mental shifting (attention switching) supports the ability to shift from one task to another. Inhibition requires suppression of irrelevant stimuli in order to focus on currently relevant information. Updating requires monitoring, coding, and updating information in working

memory in accordance with the task at hand. Ramsberger (1994) notes that executive abilities play a role in everyday communication function where there is a need to attend to a communication partner, sustain that attention, sequence information to be communicated, monitor ongoing communication, and shift strategies in accordance with ongoing conversation. Thus there is a clear need for research on the role of executive functions in language function and development of clinical tools to evaluate and treat executive impairments.

Increasing evidence for the involvement of STM and executive processing in aphasia has spurred discussion of a need to consider these processes in our evaluation of language disorders (Miyake, Emerson, et al, 2000; Martin, Kohen, & Kalinyak-Fliszar, 2010; Purdy, 2002) and development of treatment methods that address these cognitive processes (e.g., Koenig-Bruhin & Studer-Eichenberger, 2007, and others discussed in the next section). The treatment protocol employed in this study reflects this current interest in developing treatment tasks that engage STM and executive processes in order to improve language function.

STUDIES OF TREATMENT FOR STM IMPAIRMENTS IN APHASIA

In keeping with the evolving focus on processing aspects of language impairment, researchers are beginning to use computational models such as Dell's interactive activation model as frameworks to predict effects of therapy techniques such as priming or cueing based on dynamics of the treatment processes (Abel, Grande, Huber, Wilmes, & Dell, 2005; Abel, Huber, & Dell, 2009; Abel, Wilmes, & Huber, 2007; Martin, Fink, Renvall, & Laine, 2006).

Koenig-Bruhin and Studer-Eichenberger (2007) investigated the effectiveness of a treatment to improve temporary storage of verbal information by a person with reproduction conduction aphasia. They based their study on the premise that repetition and STM impairments stem from premature decay of activated representations being held in STM (Martin & Saffran, 1992). Training involved repetition of sentences that were four to seven words long with increasing delays between the stimulus and response. Gains were observed in sentence repetition as well as span for digits and words.

Majerus, Van der Kaa, Renard, Van der Linden, and Poncelet (2005) reported a treatment case study of BJ, who had a phonological short-term memory deficit and a span of three words and two nonwords. A comprehensive evaluation of his language and STM abilities revealed that although he could retain semantic information in STM, maintaining phonological information was impaired. Majerus et al (2005) used delayed repetition tasks that required holding meaningful and meaningless phonological information in STM for increasingly longer periods. They trained repetition of over 250 pairs of bisyllabic words or nonwords that differed by a single consonant. The first step was to have BJ repeat the item pairs immediately after hearing the stimuli. Once phonological production was stabilised in this condition, item pairs were repeated after a 5-second filled interval. Treatment was carried out for 16 months (twice per week) and resulted in modest improvements of digit and nonword span, nonword repetition, rhyme judgements, and by the participant's self-report, improvement in comprehension in conversational contexts involving more than two people.

Francis, Clark, and Humphreys (2003) targeted the STM deficit of a person with aphasia by requiring the repetition of sentences that gradually increased in length and complexity. Their participant, BG, presented with impaired sentence repetition and impaired comprehension. Background testing led the investigators to conclude that BG's comprehension impairment was due mainly to her STM impairment. They predicted that improvement of her STM

deficit (manifested as better repetition of longer and more complex sentences) would generalise to improved comprehension. Their prediction was confirmed in part. Improvement was observed on some measures of sentence comprehension, but BG's comprehension of sentences with reversible semantic roles was impaired as it had been prior to treatment.

These studies, as well as others that target short-term maintenance of language representations (e.g., 'spaced retrieval' therapy; Fridriksson, Holland, Beeson, & Morrow, 2005), indicate the feasibility of a treatment approach for word and sentence processing disorders in aphasia that focuses on improvement of the ability to maintain activation of the representations of words. The study presented here is another example of the growing interest in the role of cognitive support processes such as short-term memory in aphasia and how to consider these in the development of treatment protocols for aphasia. In the Discussion of the present study we offer some principles to consider as investigations of diagnosis and remediation of cognitive aspects of language processing move forward.

THE PRESENT STUDY

We present a treatment case study of FS, an individual with a language profile consistent with conduction aphasia (predominantly phonological impairment). In this case study we report a novel treatment for word processing impairments in aphasia that incorporates varying time interval conditions to strengthen the ability to maintain activation of semantic and phonological representations of words to improve language function. Specifically, treatment focused on improving FS's ability to maintain activation of words and nonwords using a repetition with delay paradigm. We predicted that improvements in language ability would be evident in the tasks used in treatment (repetition), and that her improved ability to maintain activation of words and nonwords would generalise to better performance on other language tasks that involve increased STM support (e.g., verbal span). These predictions were tested using a comprehensive language and verbal STM assessment battery developed in our laboratory (Martin et al., 2010) as a pre-and post-treatment measure.

METHOD

Participant

History—FS was a 55-year-old female. She experienced a left temporal intra-parenchymal haemorrhage in October 2005. She was 29 months post onset at the time of her enrolment in our treatment study. She was right-handed, a native speaker of English, and had a high school education. She was working as a nursing assistant prior to the onset of her stroke. FS passed an audiometric pure-tone air conduction screening at 25 dB HL for 1000, 2000, and 4000 Hz, bilaterally. Prior to her enrolment, FS gave written informed consent as approved by the Institutional Review Board of Temple University.

Language evaluation—FS was administered a number of standardised and laboratory-developed tests to determine her aphasia type and language profile. Results of these tests are shown in Table 1. Performance on the *Western Aphasia Battery* (WAB; Kertesz, 1982) classified FS as having conduction aphasia. Repetition of one-and two-syllable words was relatively spared compared to her repetition of longer words and sentences as measured by subtests of the WAB (Kertesz, 1982) and the *Philadelphia Repetition Test* (PRT; Roach, Schwartz, Martin, Grewal, & Brecher, 1996). Typically in repetition, FS gave no response or made phonological substitutions for intended target responses. Rarely did she produce semantic substitutions or attempt to paraphrase in repetition. Likewise, FS demonstrated similar lexical retrieval difficulties as shown by performance on the *Boston Naming Test* (BNT; Kaplan, Goodglass, & Weintraub, 2001). Her errors included primarily phonological

substitutions (e.g., dominoes → “domintoez”), omissions (e.g., cactus → “catus”) and repeated off-target attempts (e.g., harmonica → “harmarika, harmarka, kamaeka”). On the *Auditory Lexical Decision Test* (Martin & Saffran, 2002), FS’s ability to recognise real words was 2 *SD* below the mean proportion correct for a group of persons with aphasia (PWA) tested in our laboratory ($n = 21$; $0.88 \pm .06$). Her ability to reject nonwords was greater than 2 *SD* below the mean performance for this group of PWA ($0.91 \pm .07$). Whereas the tendency to accept nonwords as real words (false positives) has been attributed to difficulty in mapping phonemes onto lexical representations, difficulty in recognising words is associated with difficulty in mapping lexical representations onto semantics (Martin & Saffran, 2002). Consequently, FS’s scores for auditory lexical decision reflected significantly more difficulty in the phonological-lexical mapping process than in the lexical-semantic mapping process.

As shown in Table 2, FS’s scores on the *Peabody Picture Vocabulary Test* (PPVT-III; Dunn & Dunn, 1997) and the *Pyramids and Palm Trees Test, picture version* (Howard & Patterson, 1992) were 1 *SD* below the mean of a group of PWA. For the PPVT-III, the mean raw score and standard deviation of 37 PWA tested in our laboratory was 152.67 ± 26.48 ; for the *Pyramids and Palm Trees, picture version* (Howard & Patterson, 1992), the mean and standard deviation of 65 PWA (from Martin, Schwartz, & Kohen, 2006) was 89.84 ± 7.75 . In summary, results of standardised testing were consistent with mild-moderate impairment of lexical-semantic processing and a moderate-severe impairment of lexical phonological processing (see Table 1).

Pretreatment measures—To further understand the nature of FS’s input and output language-processing abilities, and in particular the interrelationship between these abilities and STM, FS was administered the *Temple Assessment of Language and Short Term Memory in Aphasia* (TALSA; Martin et al, 2010). Briefly, the TALSA is a comprehensive assessment that incorporates a STM component in measures of language processing and includes a comprehensive set of span measures that probe phonological and semantic abilities. The STM variations enable the assessment of the ability to activate and maintain activation of single and multiple word utterances in the context of comprehension, repetition, and production tasks. Specifically, the TALSA consists of two parts: *Part 1*, single and multiple word processing tasks with STM variations, and *Part 2*, span measures with language variations. The STM variations in Part 1 are designed to increase memory load inherent in the language task in two ways: (1) by adding a temporal interval between stimuli to be compared or before a response and (2) by increasing the number of items that need to be compared in judgement tasks. In Part 1 the temporal intervals are in three conditions: a 1-second unfilled (1-sec UF), a 5-second unfilled (5-sec UF), and a 5-second filled (5-sec F) condition. The 5-sec F interval condition consists of unison counting by participant and examiner random digits, 1 through 9, as they momentarily appear on the computer screen. Random counting is intended to simulate competition thereby disrupting processing of the stimuli being tested. As noted in the Introduction, a person’s span capacity varies depending on the characteristics of the stimuli to be recalled. Therefore, in Part 2, verbal span tasks are varied for content by manipulating the characteristics of the stimuli that involve processing of phonological (e.g., rhyming), lexical (e.g., word frequency), and semantic (e.g., imageability) representations of words (Martin et al, 2010). A sample of the stimuli from *Part 1* and *Part 2* of the TALSA may be found in Appendix A. FS’s pretreatment performance on the TALSA is reported in Tables 2 through 4.

In the case of output processing there was greater disparity in measures of phonological and semantic processing (Table 2). In general, FS’s performance declined on all tasks with increasing temporal interval. She demonstrated poorer performance on single word repetition (words and nonwords) and word pair repetition for phonologically related items.

Also, sentence repetition was poor for both simple subject-verb-prepositional phrase sentences and sentences padded with adjectives. Additionally, the proportion of FS's naming responses that were errors consisted of semantic (.03, 1-sec UF), mixed (.03, 5-sec UF), and nonword (.17, 1-sec UF; .20, 5-sec UF and F) substitutions (Table 2). Table 3 shows FS's performance on making word judgements with increasing memory load. For this particular task the items to be judged, semantic or phonological, were identical in both versions, but the number of pairs to be held in short-term working memory was different. As Table 3 shows, FS's ability to make similarity judgements (synonymy or rhyme) sharply declined when the number of pairs to be compared in short-term memory was increased from two to three.

Finally, measures of verbal STM span (Table 4) provided additional evidence of a phonological processing impairment. FS performed more poorly on those tests that required more phonological than semantic support (e.g., span for nonwords and low-imageability words).

In order to evaluate the severity of FS's language and STM deficits, her pre-treatment performance at the three intervals on all subtests of the TALSA was compared to the performance on these same subtests by a group of control participants without a history of aphasia or brain damage ($n = 10$) and a group of PWA ($n = 34$) both of whom were tested in our laboratory. Data for these groups are presented in Tables 5 through 7.

FS's scores on the TALSA for input and output phonological and lexical-semantic tasks, word judgement tasks, and span measures for all three intervals (Tables 2 through 4) were more than 2 *SD* below the mean scores of "typical" performance of individuals without a history of aphasia or brain damage (Tables 5 through 7). Comparison of FS's performance to that by the PWA ($n = 34$) on input and output phonological tasks and lexical-semantic tasks (Table 5) revealed the majority of her scores at the 1-sec UF, 5-sec UF, and 5-sec F intervals to be within 1 *SD* of the mean scores of this group with a few exceptions noted. For the 1-sec UF interval, FS's scores were 1 *SD* below the mean scores of the PWA for two output phonological tasks, nonword repetition and word pair repetition of unrelated pairs. At the 5-sec UF interval condition, FS's nonword repetition score remained 1 *SD* below the mean score of the PWA, but all of her scores for word pair repetition (i.e., semantically related, phonologically related, and unrelated) at this interval were now 1 *SD* below the mean scores of the PWA. For one input lexical-semantic task, FS's score was 2 *SD* below the mean scores for the PWA: sentence comprehension for reversible sentences. On the TALSA tasks that increased memory load for word judgements, FS's performance on the 2- and 3-item version was comparable to that of the group of PWA (Table 6) with scores on the 3-item version lower than those on the 2-item version. Finally on the span measures, three of FS's span scores were outside the mean span scores and standard deviations of the group of PWA (Table 7): nonword repetition span (i.e., span = 0), repetition span for low-frequency/low-imageability words, and the semantic probe memory span.

Overall, TALSA testing revealed that FS had mild impairments on input phonological and lexical-semantic processing tasks (the former being more impaired), and mild to moderate impairments on output phonological and lexical-semantic tasks. Span scores reflected detrimental performance on verbal span tasks that manipulated the phonological versus semantic characteristics of the stimuli to be recalled. In addition there was a decline in performance with increasing interval and memory load conditions. Based on these results, FS was enrolled in our novel treatment programme designed to improve activation and maintenance of phonological representations in verbal STM.

Experimental stimuli

Phonological treatment stimuli were selected from a 320-item laboratory-developed pretest of one- and two-syllable words and nonwords. Stimuli in the pretest consisted of the following phonological variations: 80 two-syllable high-imageability words, 80 three-syllable high-imageability words, 80 two-syllable nonwords, and 80 three-syllable nonwords. Imageability ratings were obtained from Paivio (2004). Stimuli were selected if they were rated four or higher in imageability. Frequency ratings were obtained from Pastizzo and Carbone (2007). Frequencies of the word stimuli ranged from medium to high (greater than 50 per million). The nonwords were derived from the real words by rearranging phonemes in words (e.g., bail → laib). However, if the resulting nonword did not conform to the phonotactic rules of standardised English, an alternative nonword was derived from the real word by changing one to two phonemes. In addition, nonwords retained the same stress pattern as their real-word counterparts.

The 320-item pretest was administered by live voice three times in random order with a request to repeat each item after a 1-second UF interval, the interval condition designated for the first application of treatment. Responses were recorded on-line and digitally recorded to verify accuracy. Items were selected as experimental stimuli if they were not repeated accurately on at least two of the three administrations of the pretest. Of these items, 20 were selected as experimental stimuli from each variation described above, so that 10 items were designated for treatment, and 10 were untrained and used for probing response generalisation. Thus, for each variation, 20 three-syllable words, 20 two-syllable nonwords, and 20 three-syllable nonwords were selected for a total of 60 stimuli. Items for the two-syllable word variation were excluded from the treatment protocol because FS performed exceptionally well on repetition of these items. A list of FS's experimental stimuli, treatment and response generalisation items, for each stimulus variation, is given in Appendix B.

Overview of (1) the treatment programme for language support processes (activation and maintenance of word representations) and (2) FS's specific treatment protocol

Table 8 summarises the treatment programme. There are two training modules, Phonological and Phonological + Semantic. Each module has two levels of stimuli that are varied in ways that stimulate access to phonological or phonological and semantic representations: *Level 1*, single word and nonwords, and *Level 2*, word pairs and triplets. Variations of stimuli within a level are hierarchically presented from easier to more difficult. In *Level 1* of the phonological module, for example, words are presented before nonwords, which require more phonological support. Word and nonword training sets are each varied by progressive increases in syllable length to promote greater reliance on phonological support. *Level 2* uses pairs and triplets of words with phonological overlap along with increasing syllable length in order to stimulate phonological processing. FS did not participate in the Phonological + Semantic Module but the components of this module are also listed in Table 8. Characteristics of words that stimulate lexical-semantic processing, such as imageability and categorical relatedness, are used in this training module.

For both Modules, the training protocol consists of the three interval conditions identical to those in the TALSA: 1-sec UF, 5-sec UF, and 5-sec F interval. Participants are assigned to a specific module and level within a module based on three factors related to their performance on the TALSA: (1) Does the activation-maintenance deficit (i.e., STM deficit) affect primarily semantic representations or phonological representations? (2) Does this deficit affect single- or multiple-word processing? (3) At what interval does performance falter?

For each level within a module, treatment is applied sequentially to the stimuli at the interval condition designated for the first application of treatment. Treatment is then applied to the *same stimuli* at the remaining interval conditions. For those participants who complete treatment at *Level 1*, they may advance to *Level 2* and the application of treatment continues as previously described.

For FS, results of her performance on the TALSA characterised her activation-maintenance deficit as one that affected primarily phonological processing of both single- and multiple-word utterances. The TALSA also revealed that performance declined initially after the 1-sec UF interval condition. Consequently, FS was enrolled into Phonological Module, Level 1 of the treatment programme with initial application of treatment at the 1-sec UF interval condition.

Experimental design

We used a single-participant, multiple-baseline, multiple-probe design across behaviours to examine acquisition and generalisation effects of treatment. The dependent variable was accuracy of repetition responses of the items in each stimulus variation at each interval condition designated for treatment. The first application of treatment was at the 1-sec UF interval, the second application was at the 5-sec UF interval, and the final application of treatment was at the 5-sec F interval. The dependent variables (i.e., items in each stimulus variation) were measured repeatedly during baseline at the interval condition designated for the first application of treatment as described above. Following baseline, a continuous probing schedule was followed for the treatment items (and untrained response generalisation items) while a reduced probing schedule (every fourth probe session) was followed for items in stimulus variations being measured in baseline. When treatment was applied consecutively to the items in the remaining stimulus variations, the probing schedule was switched so that *these* items (along with their untrained response generalisation items) were continuously probed, and the previously trained items were probed in maintenance at the reduced probing schedule. The multiple probe design was selected to control for the effects of repeated exposure to untrained stimuli (Fink, Schwartz, Sobel, & Myers, 1997; Nickels, 2002).

Baseline phase—Repetition responses were continuously measured during the baseline phase. Words and nonwords were presented in random order with a request for FS to repeat the item after the 1-sec UF interval condition. No lip cues were provided. Stable baselines were established if proportion correct of the final three baselines did not deviate by more than .30. (*Note:* After the first application of treatment, only the stimulus variations scheduled for treatment were continuously measured in baseline, while the remaining stimulus variations were probed at the reduced schedule previously described.)

Treatment phase—Probes, identical to those administered in baseline, were conducted immediately prior to the start of each treatment session. The criterion for successful acquisition of trained stimuli was initially set at .90 correct for two of three consecutive sessions. If not reached, treatment continued for a total of 12 sessions. FS was inconsistent in meeting this criterion. When treatment was initiated at the 5-sec F interval, the criterion was lowered to .80 correct in two of three consecutive sessions. Probe data for the .90 criterion level and the .80 criterion level were both graphically represented. However, we report FS's response to this treatment for the three stimulus conditions with the revised .80 criteria.

Maintenance and follow-up phase—Maintenance of previously treated items and untrained response generalisation items from stimulus variations were measured every

fourth probe session during application of treatment to subsequent items in stimulus variations. Follow-up probes were administered 3 months after completion of treatment.

Post-treatment assessment—Subtests from the TALSA were administered immediately after treatment was completed.

Treatment

In the training procedure FS repeated stimuli in the context of a hierarchical cueing procedure, with increasingly salient cues given as incorrect responses occurred (Linebaugh & Lehner, 1977; Wambaugh, Cameron, Kalinyak-Fliszar, Nessler, & Wright, 2004). FS was asked to repeat the stimulus word or nonword. Once a correct repetition response was elicited, the order of the steps was *reversed* to elicit correct repetition responses at each of the preceding steps. Treatment items were presented in random order for repetition. Three presentations of each stimulus item corresponded to a treatment session (for a total of 30 trials). The cueing hierarchy procedure is given in Appendix C.

Treatment sessions were three times per week and lasted for 45 to 60 minutes. FS received a total of 137 sessions to complete the treatment protocol for Phonological Module 1. Treatment was administered by a certified speech language pathologist (the second author) or by a student completing her final year of graduate studies in Communication Sciences and Disorders at Temple University.

Reliability

A proportion of all baseline and probe sessions were randomly selected to calculate interjudge reliability. An independent examiner listened to and transcribed digital audio recordings of .20 of all probe sessions. Point-to-point agreement between the original score and the second score was calculated to verify correct and incorrect repetition responses for treatment and response generalisation items. Mean agreement for verification of correct and incorrect repetition responses was .90 (range .70 to 1.00).

Effect sizes

The effects of treatment and outcomes of treatment were estimated by calculating effect sizes (ES) using Busk and Serlin's *d* (1992). The *d* statistic for *treatment effects* was calculated by subtracting mean baseline performance from mean performance in treatment, and for *treatment outcomes* by subtracting mean baseline performance from mean performance achieved in maintenance. Separately, each value was divided by the standard deviation of the baseline phase to estimate ES for treatment and for treatment outcomes, respectively. Beeson and Robey (2006) have reported benchmarks for the interpretation of ES for single-participant studies in acquired alexia and agraphia, and for lexical retrieval treatments. Currently no such benchmarks are available for repetition treatments. Consequently, the Shewart procedure (see Robey, Schultz, Crawford, & Sinner, 1999) was used to assist in interpretation of treatment and maintenance effects. The Shewart procedure has been used by a number of investigators to assist in the visualisation and interpretation of single-participant research design data (e.g., Farooqi-Shah, 2008; Renvall, Laine, & Martin, 2007; Tuomiranta, Kohen, Kalinyak-Fliszar, Laine, & Martin, 2010). For application of the Shewart procedure, the mean and standard deviation of baseline probe performance are calculated. Two horizontal trend lines (i.e., Shewart-chart trend lines) at two standard deviations above and below the mean are drawn across the baseline phase and extended through the treatment and maintenance phases. A significant change from baseline through treatment and maintenance is indicated if two successive probes are outside the bounds of these trend lines.

RESULTS

The proportions of items that FS repeated correctly during probe sessions at each interval condition for each of the stimulus variations in Phonological Module 1 are shown in Figure 1.

Item responses for each stimulus variation are represented on separate graphs, and these are arranged in the order in which treatment at each stimulus variation was implemented. The top graph represents treatment for the first stimulus variation (three-syllable words), the middle graph treatment for the second stimulus variation (two-syllable nonwords), and the bottom graph treatment for the final stimulus variation (three-syllable nonwords). The interval conditions at which treatment was implemented are shown across the top. In addition, Figure 1 shows Shewart-chart trend lines drawn from the baseline phase and extended through the maintenance phase for each stimulus variation and interval condition. Trend lines were added to assist in visual interpretation of the data and to estimate the magnitude of the effect sizes. Only trend lines representing $+2\ SD$ were plotted on the graphs. Finally, Table 9 lists the effect sizes for performance during acquisition and maintenance phases of treatment.

Acquisition effects: Repetition of treatment items at each interval condition

1-sec UF interval condition—FS's proportions correct for repetition responses for the initial six baselines for three-syllable words ranged from .10 to .20. Proportions correct in baseline for the two- and three-syllable nonword variations ranged from .00 to .30 and .00 to .20, respectively. As displayed in Figure 1, FS did not meet revised behavioural criteria (i.e., .80 in two of three consecutive sessions) for any stimulus variations during this interval. In general, visual inspection revealed a trend of improvement for the three stimulus variations. By contrast, Shewart-chart trend lines revealed a significant change in level of repetition performance from baseline to treatment for the three stimulus variations. As visualised in the graphs in Figure 1, of the 12 treatment probes administered during the treatment phase, 6 consecutive probe data points fell above the trend lines for three-syllable words, 5 consecutive for two-syllable nonwords, and 2 consecutive for three-syllable nonwords.

5-sec UF interval condition—Visual inspection alone revealed that FS's repetition performance was variable during the treatment phase at the 5-sec UF interval condition for the three-syllable word and three-syllable nonword stimulus variations. Her performance during treatment probes for these stimulus variations failed to meet behavioural criteria for treatment effects. FS's repetition performance for the two-syllable nonword variation met revised behavioural criteria for probe sessions 5 and 6. As shown in Figure 1, Shewart-chart trend lines supported visual inspection and corresponded to behavioural criteria for the three-syllable word and three-syllable nonword variations. Interestingly, two probe data points for both the three-syllable words and three-syllable nonword variations were well above the Shewart-chart trend line but were not consecutive as required to meet the Shewart-chart criteria for significant change. For the two-syllable nonword variation, Shewart-chart trend lines indicated a significant change from baseline to treatment for probes 5 through 12.

5-sec F interval condition—For three-syllable words, FS met the revised behavioural criteria in fewer than 12 probe sessions, achieving .80 to .90 for probe sessions 7 and 8. Despite achieving behavioural criteria, only the data point for probe session 11 fell above the Shewart-chart trend line. For two-syllable nonwords, revised criteria for the final two treatment probes were met and confirmed by the Shewart-chart trend line for significant

change. For three-syllable nonwords, behavioural criterion was not met, but the Shewart-chart trend line indicated a significant change in level of performance from baseline to treatment.

Response generalisation effects: Repetition of untrained items (treatment and response generalisation) at each interval condition

Repetition responses for response generalisation items for the initial six baselines (1-sec UF) ranged from .00 to .50 for three-syllable words; .00 to .20 for two-syllable nonwords; and .00 to .20 for three-syllable nonwords. As shown in Figure 1, although stable baseline performance was achieved for the treatment items for the three-syllable word variation at the 1-sec UF interval condition, it was not achieved, as indicated by the rising baseline, for the response generalisation items. However, the stability of baselines for the treatment items rendered it necessary to initiate treatment. In general, visual inspection of the response generalisation probe data for all stimulus variations during application of treatment at all interval conditions revealed low and variable repetition performance for all untrained items (treatment and response generalisation) in the baseline and treatment phases. Typically, FS's repetition performance for response generalisation items during the treatment phase was similar to performance during baseline with one exception: three-syllable nonwords at the 5-sec F interval condition. As shown in the graph (Figure 1), there was a trend towards improvement in FS's repetition responses in baseline, specifically during application of treatment to two-syllable nonwords. With subsequent application of treatment to three-syllable nonwords a steady trend in improvement for response generalisation items was noted for the final three probes. Although a number of probe data points for response generalisation fell above the Shewart-chart trend lines, they did not meet the Shewart-chart trend criteria.

Maintenance and follow-up effects

Maintenance of treatment effects was measured for three-syllable words and two- and three-syllable nonwords at the three interval conditions. As displayed in Figure 1, maintenance of treatment effects (applying the Shewart-chart criteria) was specific to treatment items for the two-syllable nonword stimulus variation at the 5-sec UF and F interval conditions.

Follow-up probes were administered at the 1-sec and 5-sec UF interval conditions 1 month after cessation of treatment. (*Note:* In Figure 1, follow-up probes are represented as filled and open diamonds for treatment and response generalisation, respectively.) Follow-up probes at the 1-sec UF interval condition indicated high levels of proportion correct for treatment items for all three stimulus variations. Proportions correct for response generalisation items were similar to those obtained in maintenance. For the 5-sec UF interval condition, high levels of repetition performance occurred for the treatment items for the three-syllable word and two-syllable nonword variations. Interestingly, follow-up probes for three-syllable nonwords, treatment and response generalisation, were well above probes obtained in treatment.

Effect sizes

Effect sizes for treatment and maintenance phases of Phonological Module 1 are listed in Table 9. Beeson and Robey (2006) only recommend evaluating ES by calculating the d statistic from baseline to maintenance as a measure of the magnitude of change in level of performance from pre- to post-treatment. Since the experimental design did not include a maintenance phase for the three-syllable nonword variation, an estimation of FS's change in level of performance for the treatment phase was of interest to evaluate despite the limitation of interpretation of this ES (Beeson & Robey, 2006). Effect sizes were calculated from baseline to treatment for treatment and response generalisation items for the three-syllable

nonword variation, as well as for the three-syllable word and two-syllable nonword variations. In general, the largest effect sizes were calculated for treatment and maintenance data that corresponded to stimulus variations and interval conditions that met the Shewart-chart criteria for significant change.

Post-treatment TALSA tests of language and STM abilities

Once treatment was completed, the TALSA (Martin et al, 2010) was re-administered. Results are reported in Tables 2 through 4. As shown in Table 2, FS made some gains on tests of input phonological processing. For example, she demonstrated a .15 increase in accuracy on the word rhyming pair judgement task in the 5-sec UF condition. For measures that engaged output processes (Table 2), those that relied on phonological processing showed definite improvement at both the 1-sec and 5-sec UF interval conditions. FS improved by .06 to .50 on measures of word and non-word repetition, word pair repetition, sentence repetition, and picture naming. On the word pair repetition task, FS's accuracy increased in the 5-sec UF and F interval conditions for semantically related pairs, in the 1-sec and 5-sec UF intervals for the phonologically related pairs, and in all three interval conditions for the unrelated pairs. For picture naming, FS demonstrated a .07 increase in correct naming responses at the 1-sec UF interval, and a .13 increase in correct responses at the 5-sec UF and F interval conditions. In addition, the proportion of nonword substitution errors decreased by .10 at 1-sec and 5-sec UF intervals, and by .13 at 5-sec F interval. Noteworthy improvements also were observed on the rhyming and synonymy triplet judgements for both the 2- and 3-item versions (Table 3). For example, FS's post-treatment performance increased by .20 on the 3-item version of the synonymy triplet judgement task. Finally, FS also showed improvement for a majority of the span measures (Table 4), with striking improvement on those that required activation of phonological representations in short-term memory.

Comparison of FS's post-treatment scores (Tables 2 through 4) to those of the control participants ($n = 10$) and the PWA ($n = 34$) (Tables 5 through 7) revealed stronger evidence of improvement on these TALSA measures. For example, FS's performance on the TALSA tasks that varied memory load (i.e., synonymy triplet judgements, rhyming triplet judgements) was now within the range of "typical" performance of the control participants ($n = 10$) for the 2-item versions of these tests. In addition, her score for the 3-item version (i.e., the increased load condition) of the synonymy triplet judgements was also within the range of scores for "typical" performance. For input phonological and lexical-semantic tasks, FS's performance compared to that of the PWA ($n = 34$) revealed her post-treatment scores at the 5-sec UF and F intervals to be within or greater than 1 *SD* of mean performance or better than mean performance on the following tasks: word rhyming judgements (words), category judgements, and sentence comprehension (reversible sentences). For output phonological and lexical-semantic tasks at the 5-sec UF and F intervals, FS's mean performance was either within 1 *SD* or better for word-nonword repetition, and repetition for semantically related, phonologically related, and unrelated pairs. Finally post-treatment scores on the span measures, revealed improvement to within 1 *SD* of the mean scores of the PWA on the following span measures: pointing span for digits, word-nonword repetition span, repetition span for high-frequency/low-imageability and low-frequency/low-imageability words, and the semantic probe span.

DISCUSSION

Summary of treatment results and performance on post-treatment TALSA measures

The purpose of this treatment case study was to determine the efficacy of directly treating fundamental cognitive processes that support language function: *activation of semantic and*

or phonological representations of words and maintenance of those activated representations. Many treatment approaches address the need to improve access to (i.e., activation of) language representations and use tasks such as word-to-picture matching, repetition, and naming to promote better access to language. As discussed in the Introduction, however, studies indicate that word processing deficits in aphasia involve impairments of both activation *and* maintenance of language representations that support comprehension, production, and repetition of words and sentences. The maintenance of activated representations is the short-term memory component of language processing. For treatments that target the language impairment directly in order to improve language function, it is reasonable to consider incorporating tasks in treatment that improve the STM component of language function.

The treatment chosen for FS was designed to improve activation and maintenance of phonological representations by systematic manipulation of linguistic and STM components. It was implemented as repeated repetitions of multisyllabic words and nonwords in three conditions: immediately after hearing them and in two other conditions, after a 5-second unfilled and then filled interval. The immediate repetition condition (or the 1-sec UF interval) was intended to facilitate accurate, immediate access to input and output phonological representations. The treatment was initiated with three-syllable words and progressed to two- and three-syllable nonwords. Repetition of multisyllabic words is challenging for individuals with a phonological processing impairment, as was the case with FS. However, repetition of words, supported by lexical and phonological activation, makes words typically easier to repeat than nonwords. Thus treatment for FS progressed hierarchically from stimulation of the phonological route with lexical support (word repetition) to a relatively circumscribed stimulation of the phonological route (nonword repetition). The progression from easier to more-difficult stimuli was coupled with a progression from easier to more difficult activation-maintenance conditions: minimal (1-sec UF interval before responding), short-term (5-sec UF interval before responding), and short-term in the context of verbal competition (naming random numbers on a computer screen for 5 seconds before responding).

FS's probe data provide an opportunity to appreciate the importance of multiple measures to assess treatment effects. FS progressed through the phases of treatment steadily, but did not meet behavioural criteria for the majority of stimulus variations and interval conditions, except treatment items for the three-syllable word and two-syllable nonword stimulus variations at the 5-sec F interval. Generalisation was negligible and maintenance of treatment effects, although above baseline levels for treatment items, was modest. However, the application of Shewart-chart trend lines to assist with visual inspection of the data revealed treatment and maintenance effects (for treatment stimuli) that were not evident in the behavioural criteria alone. In addition, the magnitudes of the effect sizes (Table 9) were largest for treatment and maintenance data that met the Shewart-chart criteria for significant change. On the other hand, FS *did* meet behavioural criteria for treatment items in the three-syllable word variation at the 5-sec F interval, but her probe data failed the Shewart-chart criteria. Moreover, the magnitude of the effect size calculated from baseline to treatment was the lowest for this stimulus variation and interval condition (0.73). Overall, these inconsistencies exemplify the importance of using several measures (behavioural and statistical) to examine treatment effects in acquisition, maintenance, and follow-up phases of treatment.

Our predictions that our novel STM treatment using a repetition with delay paradigm would improve FS's activation-maintenance deficit as (1) evidenced by improved language performance on the repetition measures of the TALSA and (2) generalised to better performance on other language and STM measures of the TALSA, especially in light of the

variable acquisition and maintenance effects of treatment, may be premature. Nonetheless, we would like to suggest that our predictions are not without merit and are a catalyst for investigations that are currently ongoing in our laboratory.

Our discussion will be three-fold. First we discuss how we may have facilitated stronger treatment effects for both trained and untrained items. Then we discuss why we did not observe more robust gains in acquisition and maintenance phases of treatment for trained and untrained items. Finally, we discuss the importance of FS's improved post-treatment results on subtests of the TALSA in lieu of reliability data crucial to the interpretation of these results as significant.

As revealed by the treatment graphs (Figure 1), treatment effects (treatment items only) were consistently met for the three stimulus variations at the 1-sec UF interval. This was not the case for the longer interval conditions, 5-sec UF and F. Post-hoc observation of probe data at these interval conditions revealed that treatment probe data for the final treatment probes were variable with criteria met (i.e., .80 two of three treatment probes) for some of the treatment probes. Perhaps had we been more flexible with our treatment protocol by extending treatment and administering additional probes beyond the 10 designated, we may have promoted stability of probe performance to levels that met criteria, behavioural and Shewart-chart trend line (as other investigators have demonstrated, e.g., Linebaugh, Baron, & Corcoran, 1998; Wambaugh & Ferguson, 2007). As for the negligible response generalisation effects, support for extending probing is also suggested by the response generalisation probe data. Visualisation of the response generalisation probes (Figure 1) shows that many of the data points were close to the Shewart-chart trend line for treatment effects, while others were above the trend line but did not meet the Shewart-chart line criteria. This is specifically relevant for the three-syllable nonword response generalisation items at the 5-sec F interval condition. The data strongly suggest that extending probing beyond 10 probe sessions, criteria (especially for the Shewart-chart trend line) may have been met (as shown by the final response generalisation probe which was above the trend line). Although maintenance and follow-up effects were specific to treatment items, our treatment design did not allow for probing of treatment and response generalisation items at previously treated interval conditions. Perhaps probing at previously applied interval conditions would have demonstrated maintenance effects. Of note, the most robust treatment effects at follow-up were for the three-syllable non-words, treatment and response generalisation items, at the 5-sec UF interval condition (proportion correct .70 and .50, respectively). These items represent the most difficult stimulus variation coupled with the most difficult activation-maintenance condition. The improvements in this condition and stimulus variation lend support to the hypothesis that targeting the underlying cognitive support process (activation-maintenance) can be an effective treatment strategy. However, this only could be confirmed by additional follow-up probes, which we did not administer.

This treatment approach differs from other treatments for word processing in aphasia in the following way: The focus is on improving a fundamental ability, maintenance of activated linguistic representations that supports language performance. Other treatments that we have developed have been designed more specifically to maximise generalisation to untrained items. For example, in the contextual priming paradigm (e.g., Martin, Fink, Laine, & Ayala, 2004), words in the training conditions are semantically or phonological similar because the interactive activation model that frames those studies (Dell & O'Seaghdha, 1992) postulates that such similarities among words being produced should promote spreading activation to untrained related items, increasing the potential for those items to be retrieved successfully.

As previously stated we *did* anticipate, a priori, that we would observe more robust gains in acquisition and maintenance phases of treatment for trained and untrained items. If an

improved ability to maintain activation of phonological representations results in better performance on other tasks, we might expect to see this improvement in the treatment and generalisation stimuli. In retrospect, however, there are two potential reasons why such improvements were not observed. First, the modest or negligible gains during treatment and maintenance phases are consistent with the lack of systematic manipulation of the stimuli to promote generalisation such as that used in contextual priming. The words were unrelated semantically or phonologically and nonwords are only related in that they are nonwords. These stimuli would not promote much spreading activation within the semantic-lexical-phonological network. For example, Davis, Harrington, and Baynes (2006) implemented an intensive semantic treatment with their participant with Wernicke's aphasia based on their review of the literature, which indicated that semantic treatments facilitate activation of semantic networks to promote generalisation effects for naming, while phonological treatments do not (e.g., Coelho, McHugh, & Boyle, 2000, Kiran, Thompson, & Hashimoto, 2001; see also Davis et al, 2006). Second, another finding in our studies of contextual priming treatments might be at play here. Martin et al (2004) have found that training on tasks involving repeated trials of repetition or naming leads to increased competition during facilitation, but after 5 minutes retrieval of trained words in a post-test is improved. The account of immediate interference during training followed by short-term gains is twofold: Training induces a small set of words to become activated to similar levels within the lexicon and therefore there is greater competition among them. After 5 minutes their activations decline but remain at high enough levels to be easier to retrieve than before training. Those results pertain to a facilitation study, but we are also observing this pattern in the context of treatment studies ongoing in our lab. At this juncture we can only say we have some evidence for this account of weak effect sizes during treatment and maintenance phases. However, that evidence is intriguing enough to investigate this possibility further, which we are doing.

We understand that the purpose of any pre- and post-treatment language assessment is the valid and reliable measurement of the language impairment. The purpose of the TALSA battery is to understand the inter-relationship of input and output language-processing abilities and short-term memory abilities. To our knowledge there are no tests currently available that measure language and STM abilities in such a way as the TALSA. Thus we cannot underestimate the importance of the results of the TALSA. Our goal is to collect reliability data on the TALSA battery that will unequivocally demonstrate the consistency and stability of the scores of language and short-term memory that it measures. However, the results of the post-testing on the TALSA relative to FS's performance are of particular interest and may have broader implications for aphasia rehabilitation.

One of the most sought-after outcomes in treatment research is generalisation of improvement on one task or stimulus type to other untrained tasks or stimuli. Following treatment, FS showed improvement on a number of phonological and semantic TALSA subtests that were not part of the treatment protocol but engaged cognitive support processes that were integral to this treatment. She improved on three language tasks with variations that increase working memory load: word pair repetition, synonymy triplet judgements, and rhyming triplet judgements. Gains on these tasks reflect an improved ability to maintain activation of representations that generalises to tasks other than those used for training. The improvement in the word pair repetition task is impressive, as this task increases short-term memory load in two ways: increasing the number of items to be repeated and imposing a temporal interval before the response. Also, consider FS's improvement on both the 2-item and 3-item versions of the synonymy and rhyming triplet judgement tasks (Table 3) which stress working memory load by varying the number of word pairs to be compared and maintained in short-term working memory (Kohen, Martin, Kalinyak-Fliszar, Bunta, & DiMarco, 2007; Martin et al, 2010). When the task is to decide which two of three words are

most similar in meaning (e.g., *jail*, *cage*, *prison*) or which rhyme (e.g., *bake*, *stake*, *cane*), three word pairs must be held and compared in short-term working memory (*bake–stake*, *stake–cane*, and *bake–cane*). When the task is which of two words (e.g., *jail*, *cage*) is most similar to a third (*prison*), only two word pairs need to be held and compared in short-term working memory (*prison–jail*, *prison–cage*). FS also improved on six of our seven direct measures of verbal STM span. Also, although the treatment targeted phonological processes, improvements on semantic tasks were observed as well. These results indicate that the training protocol can improve activation and maintenance processes that support language function resulting in better performance on a variety of language tasks that are supported by these fundamental abilities.

Relevance of treating STM and executive function aspects of word processing

Verbal STM impairments are pervasive in aphasia. Individuals with mild aphasia or seemingly no residual aphasia may still have difficulty with short-term retention of language. It is not uncommon for individuals with mild or moderate aphasia to complain of language difficulty in day-to-day conversational situations. It is in these contexts that short-term memory and executive functions that support language production and comprehension are most challenged. Application of treatment at the 5-second unfilled and filled interval conditions is intended to integrate these two cognitive support processes directly *in the context of a language task*. The goal is not necessarily limited to increasing verbal STM capacity or improving executive abilities such as inhibition or set shifting. Rather, direct treatment of managing these three components of language use, activation of language representations, maintenance of that activation in quiet (i.e., 5-sec UF) and in competing (5-sec F) contexts, improve “coordination” of these support processes with language abilities. The importance of the roles of STM and executive functions in the rehabilitation of the language impairment in aphasia is a relatively new area of research. Some researchers have focused on improving attentional skills to improve language abilities (e.g., Sinotte & Coelho, 2007; Mayer & Murray, 2002). Our approach is one in which we hierarchically increased STM and executive processing load in the context of the language task used for training.

Application of this treatment to different levels of severity of aphasia

The protocol for this treatment study is quite extensive. However, it has been designed so that participants may be entered into the treatment protocol at the module and interval condition based on their performance on the TALSA. As previously discussed, three factors relative to performance on the TALSA must be considered before assignment to a specific module and level within a module: (1) Does the activation-maintenance deficit (i.e., STM deficit) affect primarily semantic representations or phonological representations? (2) Does this deficit affect single- or multiple-word processing? (3) At what interval does performance falter? We have recently completed or are carrying out this protocol with three other individuals with aphasia. One person with a moderate to severe Wernicke’s aphasia was enrolled in the phonological and semantic module (Martin, Kohen, McCluskey, Kalinyak-Fliszar, & Gruberg, 2009) and two others with phonological production difficulties were enrolled in the phonological module. One began with nonword stimuli and the other with word stimuli (Tuomiranta et al, 2010). These cases exemplify the flexibility of this protocol. It is not necessary or recommended that participants always be assigned to Phonological Module 1, three-syllable words at the 1-sec UF interval condition if performance on the TALSA determines otherwise. In addition, the treatment protocol may be adapted to a variety of treatment stimuli and treatment tasks. Finally, any treatment programme tested in the laboratory should be based on guiding principles that can be extracted and integrated into a clinical setting. Below we describe several principles that we believe are inherent in the treatment programme reported here and which are consistent with

the perspective on the nature of language impairment in aphasia that we have proposed in this study. These principles are operational in that they are proposed as part of an overall programme of research on the involvement of STM and executive processes in aphasia:

1. Aphasia is primarily a disturbance of processes that support language function, including the ability to (a) activate language representations, (b) maintain that activation for the duration of a language task, and (c) maintain it in the context of competition.
2. The severity of aphasia is a reflection of the severity of impairment to these support processes.
3. Therapy for language disorders should be designed to incorporate STM and executive processing in a way that simulates to some degree the functional conditions in which language is used.
4. The degree to which a treatment task simulates real life conversational situations may depend on the severity of impairment. Treatment may begin with structured language tasks with increasing STM and executive function demands, but should progress towards language tasks that involve STM and executive function demands in a more natural speaking context (e.g., sharing the details of a recipe with a friend).

These principles are somewhat preliminary and are not comprehensive. Rather, some may be modified and others added as we uncover more about the interrelationship of language, STM and executive processes. We offer them here as part of a dialogue/discussion on the value and means of incorporating tasks to improve cognitive processes that support language function into rehabilitation approaches for aphasia.

CONCLUSION

This study provides support for the view that language impairment in aphasia is not just a linguistic impairment, but involves short-term memory and executive processes that mediate activation, retrieval, and short-term maintenance of representations that support language function. Treatment of these fundamental cognitive support processes in the context of a simple language task (repetition) resulted in improved language performance as measured by the TALSA on tasks other than the treatment task (e.g., synonymy judgement tasks), which also require short-term maintenance of activated language representations. The importance of these results for the rehabilitation of aphasia cannot be underestimated. Although the TALSA is unique in that it incorporates a STM component in measures of language processing and includes a comprehensive set of span measures that probe phonological and semantic abilities, caution in interpreting these treatment results relative to improvements on the TALSA is recommended until the psychometric properties of the TALSA are unequivocal. Nevertheless this treatment protocol is guided by fundamental principles of practice that can be applied to a variety of treatment tasks and protocols.

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APPENDIX A

TALSA, Part 1 and Part 2: Sample stimuli with instructions for administration

TALSA Part 1. STM variation 1: Single and multiple word processing tasks with interval conditions

Input phonological and lexical-semantic tasks

1 Phoneme discrimination

Examiner: “You will hear two words (or nonwords). Tell me if they are the same or different.”

Word

FUNNEL TUNNEL

FUNNEL FUNNEL

Nonword

blək blɛf

blək blək

2 Rhyme judgements

Examiner: “You will hear two word (or nonwords). Tell me if they are the same or different.”

Word

BREAK STEAK

DRIP FLOCK

Nonword

vin dʒrin

tud lʌd

3 Lexical comprehension

Examiner: "Listen to the word. After the cue, four pictures will appear. Point to the picture that matches the word."

Target: BED

Distractors:

4 Category judgements

Picture

Examiner: "You will see two pictures. Tell me if they are in the same category."

Example 1.

Example 2.

Output phonological and lexical-semantic tasks

5 Word-nonword repetition

Examiner: "You will hear a word (or a nonword). After you hear the word, you will repeat it as best you can."

Word

OVEN

Nonword

elek

6 Word pair repetition

Examiner: "You will hear 2 words. After you hear the 2 words, repeat them in the same order in which you heard them."

Semantically Related: BROCCOLI ONION

Phonologically Related: DENTIST DOLPHIN

Unrelated: ANKLE THEATER

7 Word triplet repetition

Examiner: “You will hear three words. After you hear the three words, repeat them in the same order in which you heard them.”

Semantically Related: SUBWAY AIRPLANE JEEP

Phonologically Related: BUCKET BATTERY BAT

Unrelated: BABY FOREST GUM

8 Sentence Repetition

Examiner: “You will hear a sentence. After you hear the sentence, try to repeat it exactly as you heard it.”

Unpadded: THE BOY IS WALKING THE DOG IN THE PARK.

Padded: THE TALL BOY IS WALKING THE SHAGGY DOG IN THE PUBLIC PARK.

TALSA Part 1. STM variation 2: Increasing memory load for word judgement tasks

9 Synonymy triplet judgements

Examiner: “You will see and hear three words. After you listen to all three words, you will point to the two words that are closest in meaning.”

LAWYER* ATTORNEY* POLICEMAN

TO START* TO CONTINUE TO BEGIN*

10 Rhyming triplet judgements

Word

Examiner: “You will see and hear three words. After you listen to all three words, you will point to the 2 words that rhyme.”

SHED* HEAD* NET

Picture

Examiner: “You will see and hear the names of three pictures. After you see and listen to all three names, you will point to the two pictures that rhyme.”

TALSA Part 2. Span measures with language variations

11 Word and nonword repetition span

List Length 3

Examiner: “You will hear a sequence of three words (or nonwords). After you hear the words (or nonwords), repeat all of the words (or nonwords) in the same order in which you heard them.”

Word

BROOM FISH NEEDLE

Nonword

blim vu/nɪsəl

12 Repetition span for words varied for frequency (F) and imageability (I)

List Length 3

Examiner: “You will hear a sequence of words. Repeat the words in the same order in which you heard them.”

HiF-HiI: WORLD TABLE WEAPON

HiF-LoI: POWER LIFE DISEASE

LoF-HiI: COTTAGE FROG CANDY

LoF-LoI: SHAME EXCUSE HINDRANCE

13 Probe memory span

Identity

Examiner: “You will hear a sequence of words. After a brief interval, you will hear another word. Tell me if the last word matches any of the words you heard before.”

APPLE SWING DOT WAIST

TRAIN NOSE* HARP NOSE*

Semantic

Examiner: “You will hear a sequence of words. After a brief interval, you will hear another word. Tell me if the last word is in the same category as any of the words you heard before.”

SPOON TOILET SUBMARINE CALENDAR

FENCE SPIDER* RAISIN LADYBUG*

Phonological

Examiner: “You will hear a sequence of words. After a brief interval, you will hear another word. Tell me if the last word rhymes with any of the words you heard before.”

JACKET HARP GRAPES STORE

BUTTERFLY HEART* NECK CART*

APPENDIX B

FS's treatment and response generalization items for word and nonword variations in Phonological Module 1

Treatment items	Response generalization items
3-syllable word variation	
avalanche	pyramid

Treatment items	Response generalization items
crucifix	nightingale
photograph	microscope
gingerbread	character
ignition	submarine
physician	screwdriver
cardinal	gondola
amethyst	albatross
pendulum	propeller
mechanic	icicle

2-syllable nonword variation			
Word derivation		Word derivation	
litlɪf	(<i>leaflet</i>)	wɪdlɪk	(<i>liquid</i>)
pekən	(<i>payment</i>)	pobɪn	(<i>poet</i>)
mastup	(<i>costume</i>)	sorkəl	(<i>sewer</i>)
kʌtrɪʃ	(<i>country</i>)	mærdʒəl	(<i>journal</i>)
wɒnfər	(<i>footwear</i>)	benwɒn	(<i>whalebone</i>)
tʊʃɪk	(<i>tunic</i>)	dænkəl	(<i>cattle</i>)
brækfɪn	(<i>fabric</i>)	trʌŋkɪn	(<i>monkey</i>)
wəsər	(<i>cigar</i>)	kalkrɪt	(<i>concert</i>)
wɪdʒəlz	(<i>measles</i>)	mʌbəlɪd	(<i>bubble</i>)
sɪnpɹɛp	(<i>princess</i>)	dʒʌndɪf	(<i>dungeon</i>)

3-syllable nonword variation			
Word derivation		Word derivation	
tʃə.nə.tʃər	(<i>furniture</i>)	mɛ.lə.ko	(<i>telephone</i>)
nə.dæ.bə	(<i>banana</i>)	kar.zɛ.fən	(<i>carnation</i>)
stɛn.vɪ.bjəl	(<i>vestibule</i>)	lɛnd.gr.ʌ.θər	(<i>grandmother</i>)
fə.spər.dəl	(<i>hospital</i>)	a.pər.pri	(<i>property</i>)
mæk.ə.gon	(<i>saxophone</i>)	bai.skə.krɒp	(<i>microscope</i>)
kɪ.bɪ.vəl	(<i>vehicle</i>)	ɛn.fə.ri	(<i>referee</i>)

APPENDIX C

Treatment cueing hierarchy

The application of the steps of the hierarchy was response contingent. The steps were applied sequentially until a correct repetition response was elicited. Then the order of the steps was reversed to elicit correct responses at each of the preceding steps. In the event that an incorrect response occurred during the hierarchy reversal, the order of the hierarchy steps was again reversed until a correct response was obtained. (Note: Step 1 is identical to probe. No visual cues are given. Visual cues are given for steps 2 through 5 of the cueing hierarchy.)

1. Word/nonword is presented for repetition and delay is imposed (i.e., 1-sec UF, 5-sec UF, or 5-sec F). Repetition is requested after delay: "Repeat the word." Feedback is given for correct/incorrect response. If correct, next word/nonword present. If incorrect, Step 2 is presented.

2. Word/nonword is presented for repetition. Delay is imposed. Repetition is requested: "Repeat the word/nonword." Feedback given for correct/incorrect response. Step 3 is presented.
3. Participant's error is reproduced followed by correct production of the stimulus (e.g., "You are saying fofograph. It is not fofograph. It is photograph."). Delay is imposed. Repetition requested: "Repeat the word." Feedback is given for correct/incorrect response. Step 4 is presented.
4. Participant's error is reproduced followed by the correct production of the stimulus (e.g., "Listen. You are saying fofograph. It's not fofograph. It's photograph."). Then each error sound or pattern is targeted with an example of the error and the correct production (e.g., "It is not /f/ as in phone. It's /t/ as in tone."). Delay is imposed. Repetition is requested: "Repeat the word." Feedback is given for a correct/incorrect response. If incorrect, the participant's error is produced again (e.g., "You are saying fofograph. It is photograph.") then a cue for the location of the error in the syllable is given (e.g., "It is the middle sound of the first syllable."). The error sound(s) are targeted in the stimulus (e.g., "It is photo, photograph."). Delay is imposed. Repetition is requested: "Repeat the word/nonword." Feedback is given for correct/incorrect response. Step 5 is presented.
5. Each syllable is targeted in the stimulus at the interval condition at which treatment is applied. Post-it notes are placed in front of the participant as visual cues to represent syllable boundaries. Each syllable is produced. Delay is imposed. Repetition is requested: "Repeat the syllable." This procedure is followed for each syllable. If all syllables are correct, the word/nonword is presented for repetition. Delay is imposed. Repetition is requested: "Repeat the word/nonword." If word/nonword is incorrect, syllable procedure is presented again. If any syllable is incorrect, Step 6 is presented.
6. Stimulus is produced. No repetition is requested. Next stimulus is presented.

Figure 1. FS's proportion correct repetition responses during probe sessions for interval conditions and stimulus variations in Phonological Module 1.

TABLE 1

Pretreatment standardized language evaluation

Measure	Score
<i>Western Aphasia Battery</i>	
<i>Information content</i>	9/10
<i>Fluency</i>	6/10
<i>Comprehension</i>	
Yes/no questions	45/60
Auditory word recognition	53/60
Sequential commands	41/80
<i>Repetition</i>	50/100
<i>Naming</i>	
Object naming	53/60
Word fluency	11/20
Sentence completion	10/10
Responsive speech	10/10
<i>Aphasia Quotient</i>	70.6
<i>Aphasia Classification</i>	Conduction
<i>Boston Naming Test</i>	32/60
<i>Philadelphia Repetition Test (n=175)</i>	
1-syllable	77/100
2-syllable	33/52
3- and 4-syllable	10/23
<i>Peabody Picture Vocabulary Test IIIA</i>	
Raw Score	129
Standard Score	66
<i>Pyramid and Palm Trees</i>	
Picture	45/52
Word	46/52
<i>Auditory Lexical Decision</i>	
Words	30/40
Nonwords	26/40

TABLE 2

TALSA Part 1. STM variation 1: Single and multiple word processing tasks with three interval conditions (between stimuli or before a response): 1-second unfilled (1-sec UF), 5-second unfilled (5-sec UF) and 5-second filled (5-sec F)

Input phonological and lexical-semantic tasks	Pretreatment			Post treatment		
	Interval condition			Interval condition		
	1-sec UF	5-sec UF	5-sec F	1-sec UF	5-sec UF	5-sec F
Phoneme discrimination						
Word (n = 20)	0.90	0.95	0.80	0.95	0.90	0.85
Nonword (n = 20)	0.85	0.85	0.70	0.90	0.85	0.75
Rhyme judgements						
Word (n = 20)	0.90	0.80	0.75	0.90	0.95	0.70
Nonword (n = 20)	0.90	0.85	0.85	0.95	0.90	0.70
Lexical comprehension (n = 16)	0.94	1.00	0.94	1.00	1.00	0.94
Category judgements – pictures (n = 20)	0.90	0.90	0.65	1.00	1.00	0.95
Sentence comprehension (n = 19)						
Reversible	0.56	0.56	0.33	0.56	0.56	0.67
Lexical	1.00	0.80	1.00	0.80	0.70	0.80
Output phonological and lexical-semantic tasks						
I. Single word processing tasks						
Word-nonword repetition						
Word (n = 15)	0.87	0.73	0.40	0.73	0.80	0.40
Nonword (n = 15)	0.13	0.07	0.07	0.13	0.13	0.07
II. Multiple word processing tasks						
Word pair repetition						
Semantically Related (n = 10)	0.50	0.20	0.30	0.40	0.40	0.40
Phonologically Related (n = 10)	0.30	0.10	0.20	0.40	0.60	0.20
Unrelated (n = 10)	0.10	0.10	0.10	0.30	0.40	0.50
Word triplet repetition						
Semantically Related (n = 10)	NA	NA	NA	0.10	0.10	0.00
Phonologically Related (n = 10)	NA	NA	NA	0.00	0.00	0.00
Unrelated (n = 10)	NA	NA	NA	0.00	0.00	0.00

<i>Input phonological and lexical-semantic tasks</i>	<i>Pretreatment</i>				<i>Post treatment</i>			
	<i>Interval condition</i>		<i>Interval condition</i>		<i>Interval condition</i>		<i>Interval condition</i>	
	1-sec UF	5-sec UF	1-sec UF	5-sec F	1-sec UF	5-sec UF	1-sec UF	5-sec F
Sentence repetition								
Unpadded (n = 50)	0.62	0.56	0.60	0.54	0.60	0.64	0.46	
Padded (n = 80)/Post Tx (n = 70)	0.36	0.30	0.41	0.30	0.41	0.41	0.39	
Picture naming (n = 30)								
Semantic *	0.80	0.77	0.87	0.80	0.00	0.90	0.93	
Mixed *	0.03	0.00	0.00	0.00	0.00	0.00	0.00	
Nonword *	0.00	0.03	0.07	0.00	0.07	0.00	0.00	
	0.17	0.20	0.07	0.20	0.07	0.10	0.07	

* Picture Naming Errors

TABLE 3

TALSA Part 1. STM variation 2: Increasing memory load for word judgement tasks

	Pretreatment		Post treatment	
	2-item version	3-item version	2-item version	3-item version
Synonymy Triplet judgements (n = 4D) *	0.85	0.73	0.93	0.93
Rhyming Triplet judgements (n = 3D) **	0.87	0.76	0.97	0.77

* Words

** Pictures

Note: Results have been corrected for chance.

TABLE 4

TALSA Part 2. Span measures with language variations

	Pretreatment	Post treatment
Digit and Ward Span *		
Digits (ISO)		
pointing	3.2	4.0
repetition	3.6	3.2
Words (ISO)		
pointing	3.0	NA
repetition	2.4	2.2
Word and Nonword Repetition Span *		
Word	1.6	2.4
Nonword	0.0	0.8
Repetition span for words varied for frequency (F) and imageability (I) *		
HiF-HiI	1.4	2.4
HiF-LoI	1.0	1.4
LoF-HiI	1.8	0.8
LoF-LoI	0.4	1.4
Probe memory Span **		
Identity	10.92	NA
Semantic	1.00	1.67
Phonological	1.93	2.97

* Maximum string length = 7 items

** Maximum string lengths: Identity = 12, Semantic = 7, Phonological = 7

TALSA Part 1. STM variation 1: Single and multiple word processing tasks with three interval conditions (between stimuli or before a response): 1-second unfilled (1-sec UF), 5-second unfilled (5-sec UF) and 5-second filled (5-sec F)

TABLE 5

		Control participants (n = 10)			PWA (n = 34)		
<i>Input phonological and lexical-semantic tasks</i>		Interval condition			Interval condition		
Phoneme discrimination		1-sec UF	5-sec UF	1-sec F	1-sec UF	5-sec UF	1-sec F
<i>Word (n = 20)</i>	M	0.99	1.00	0.96	0.95	0.93	0.87
	SD	0.02	0.00	0.06	0.07	0.10	0.10
	Range	.95–1.00	1.00	.85–1.00	.80–1.00	.55–1.00	.70–1.00
<i>Nonword (n = 20)</i>	M	1.00	0.98	0.95	0.92	0.90	0.80
	SD	0.02	0.04	0.06	0.10	0.08	0.12
	Range	.95–1.00	.95–1.00	.85–1.00	.70–1.00	.75–1.00	.55–.95
Rhyme judgements							
<i>Word (n = 20)</i>	M	0.99	1.00	0.97	0.86	0.85	0.78
	SD	0.02	0.02	0.05	0.14	0.15	0.14
	Range	.95–1.00	.95–1.00	.85–1.00	.45–1.00	.45–1.00	.35–.95
<i>Nonword (n = 20)</i>	M	0.97	0.96	0.97	0.82	0.80	0.75
	SD	0.03	0.05	0.05	0.16	0.16	0.16
	Range	.90–1.00	.85–1.00	.85–1.00	.35–1.00	.45–1.0	.45–.95
Lexical comprehensions (n = 16)							
	M	1.00	1.00	1.00	0.96	0.97	0.90
	SD	0.00	0.00	0.00	0.08	0.06	0.13
	Range	1.00	1.00	1.00	0.63–1.0	.69–1.0	.56–1.0
Category judgements – pictures (n = 20)							
	M	0.98	0.98	0.96	0.94	0.91	0.84
	SD	0.08	0.03	0.05	0.07	0.10	0.13
	Range	.75–1.00	.95–1.00	.85–1.00	.70–1.0	.60–1.0	.55–1.0
Sentence comprehension (n = 19)							
<i>Reversible</i>	M	0.89	0.98	0.90	0.67	0.67	0.69
	SD	0.14	0.05	0.12	0.22	0.21	0.17
	Range	.56–1.00	.89–1.00	.67–1.00	.33–1.0	.33–1.0	.33–1.0
<i>Lexical</i>	M	1.00	1.00	1.00	0.92	0.91	0.88

	Control participants (n = 10)				PWA (n = 34)			
	SD	0.00	0.00	0.00	0.12	0.14	0.16	
<i>Output phonological and lexical-semantic tasks</i>								
I. Single word processing tasks								
Word-nonword repetition								
<i>Word (n = 15)</i>								
M		0.99	0.99	0.98	0.80	0.79	0.67	
SD		0.02	0.02	0.06	0.20	0.29	0.28	
Range		.93–1.00	.93–1.00	.80–1.00	.33–1.0	.07–1.0	0.0–1.0	
<i>Nonword (n = 15)</i>								
M		0.93	0.83	0.75	0.47	0.42	0.16	
SD		0.11	0.22	0.22	0.30	0.31	0.21	
Range		.67–1.00	.33–1.00	.20–.97	.13–1.0	0.0–.93	0.0–.67	
II. Multiple word processing tasks								
Word Pair repetition								
<i>Semantically related (n = 10)</i>								
M		0.99	0.99	0.96	0.59	0.61	0.45	
SD		0.03	0.03	0.05	0.38	0.39	0.39	
Range		.90–1.00	.90–1.00	.90–1.00	0.0–1.0	0.0–1.0	0.0–1.0	
<i>Phonologically related (n = 10)</i>								
M		1.00	0.99	0.94	0.57	0.57	0.34	
SD		0.00	0.03	0.10	0.38	0.41	0.34	
Range		1.00	.90–1.00	.70–1.00	0.0–1.0	0.0–1.0	0.0–1.0	
<i>Unrelated (n = 10)</i>								
M		0.99	1.00	0.99	0.63	0.63	0.40	
SD		0.03	0.00	0.03	0.37	0.37	0.32	
Range		.90–1.00	1.00	.90–1.00	0.0–1.0	0.0–1.0	0.0–1.0	
Word triplet repetition								
<i>Semantically related (n = 10)</i>								
M		1.00	0.96	0.92	0.46	0.40	0.27	
SD		0.00	0.05	0.09	0.42	0.40	0.30	
Range		1.00	.90–1.00	.70–1.00	0.0–1.0	0.0–1.0	0.0–1.0	
<i>Phonologically related (n = 10)</i>								
M		0.97	0.96	0.82	0.32	0.31	0.18	
SD		0.07	0.07	0.16	0.36	0.37	0.25	
Range		.80–1.00	.80–1.00	.60–1.00	0.0–1.0	0.0–1.0	0.0–1.0	
<i>Unrelated (n = 10)</i>								
M		0.92	0.91	0.80	0.38	0.37	0.18	

		Control participants (n = 10)			PWA (n = 34)		
Sentence repetition <i>Unpadded (n = 50)</i>	SD	0.10	0.13	0.21	0.39	0.39	0.28
	Range	.70–1.00	.60–1.00	.50–1.00	0.0–1.0	0.0–1.0	0.0–1.0
	M	1.00	0.98	0.97	0.71	0.67	0.55
	SD	0.01	0.02	0.05	0.30	0.33	0.32
	Range	.96–1.00	.96–1.00	.88–1.00	.02–1.00	.04–1.0	.02–1.0
	M	0.93	0.86	0.71	0.56	0.51	0.40
	SD	0.05	0.11	0.12	0.32	0.30	0.25
	Range	.83–1.00	.69–1.00	.52–1.00	0.0–.97	.04–.96	0.0–.83
Picture naming (n = 30)	M	0.98	0.98	0.96	0.68	0.62	0.67
	SD	0.03	0.03	0.05	0.32	0.31	0.31
	Range	.93–1.00	.93–1.00	.90–1.00	0.0–1.0	0.0–1.0	0.0–1.00

TABLE 6

TALSA Part 1. STM variation 2. Increasing load for word judgement tasks

	Control participants (n = 10)			PWA (n = 34)	
	2-item version	3-item version	2-item version	2-item version	3-item version
Synonymy Triplet judgements (n = 40) *					
M	0.96	0.93	0.87		0.75
SD	0.04	0.06	0.11		0.17
Range	.88–1.00	.85–1.00	.53–1.0		.38–1.0
Rhyming Triplet judgements (n = 30) **					
M	1.00	0.96	0.86		0.74
SD	0.01	0.08	0.16		0.19
Range	.97–1.00	.80–1.00	.40–1.00		.23–1.00

* Words

** Pictures

Note: Results have been corrected for chance.

TABLE 7

TALSA Part 2. Span measures with language variations

		Control participants (n = 10)	PWA (n = 34)
Digit and Word Span * Digits (ISO)			
<i>Pointing</i>			
	M	6.58	3.36
	SD	0.79	1.81
	Range	4.60–7.00	1.00–6.80
<i>Repetition</i>			
	M	6.54	3.62
	SD	0.75	1.72
	Range	4.60–7.00	0.0–6.30
Words (ISO)			
<i>Pointing</i>			
	M	5.56	2.95
	SD	0.92	1.17
	Range	4.20–7.00	1.0–5.50
<i>Repetition</i>			
	M	5.58	3.13
	SD	1.13	1.33
	Range	4.00–7.00	1.0–6.0
Word and Nonword Repetition Span *			
<i>Word</i>			
	M	4.84	2.70
	SD	0.25	1.35
	Range	4.20–5.00	0.0–5.0
<i>Nonword</i>			
	M	3.17	1.52
	SD	0.58	0.95
	Range	2.00–3.80	0.0–4.40
Repetition span for words varied for frequency (F) and imageability (I) *			
<i>HiF-Hil</i>			
	M	4.93	2.50
	SD	0.80	1.35
	Range	4.00–6.00	0.0–4.80
<i>HiF-Lol</i>			
	M	4.60	2.27
	SD	1.01	1.40
	Range	3.00–6.00	0.0–4.80
<i>LoF-Hil</i>			
	M	4.50	2.00
	SD	0.79	0.85

		Control participants (n = 10)	PWA (n = 34)
	Range	3.00–6.00	0.0–4.40
<i>LoF-Lol</i>			
	M	4.40	2.05
	SD	0.77	1.35
	Range	3.00–5.40	0.0–4.40
Probe memory span **			
<i>Identity</i>			
	M	11.70	1.77
	SD	0.80	0.68
	Range	9.88–12.00	.80–12.0
<i>Semantic</i>			
	M	5.92	3.44
	SD	0.89	1.52
	Range	4.64–7.00	.50–6.27
<i>Phonological</i>			
	M	6.53	3.80
	SD	1.06	2.04
	Range	3.73–7.00	.53–7.0

* Maximum string length = 7 items

** Maximum string lengths: Identity = 12, Semantic = 7, Phonological = 7

TABLE 8

Protocol for treatment of short-term word activation and maintenance impairments: 1-second unfilled (1-sec UF), 5-second unfilled (5-sec UF), and 5-second filled (5-sec F)

Phonological Module	Interval condition		
Variations	1-sec UF	5-sec UF	5-sec F
<i>Level 1</i>			
Hi Image- 2-Syllable words	1	1	1
Hi Image- 3-Syllable words	2	2	2
2-Syllable words	3	3	3
3-Syllable words	4	4	4
<i>Level 2</i>			1
Phonological unrelated/related word pairs	1	1	1
Phonological unrelated/related word triplets	2	2	2
Phonological + Semantic Module			
Variations	1-sec UF	5-sec UF	5-sec F
<i>Level 1</i>			
Hi Image- Hi Freq 2-Syllable words	1	1	1
Hi Image- Lo Freq 2-Syllable words	2	2	2
<i>Level 2</i>			
Categorically related word pairs			
Hi Image- Hi Freq 2-Syllable words	1	1	1
Hi Image- Lo Freq 2-Syllable words	2	2	2

TABLE 9
Effects sizes for treatment and maintenance phases of Phonological Module 1 (Treatment and response generalization)

Interval condition	Stimulus variations	Treatment		Response generalization	
		Treatment	Maintenance	Treatment	Maintenance
1-Sec UF	3-syllable word	5.16 [*]	3.23 [*]	0.77	0.73
	2-syllable word	2.56 [*]	2.96 [*]	0.68	2.05
	3-syllable word	3.78 [*]	NA	1.38	NA
5-Sec UF	3-syllable word	1.35	0.77	-0.08	1.33
	2-syllable word	2.60 [*]	2.83 [*]	0.06	0.22
5-Sec F	3-syllable word	1.26	NA	1.41	NA
	3-syllable word	0.73	1.29	-1.10	0.12
	2-syllable word	2.15 [*]	3.46 [*]	0.71	2.04
	3-syllable word	1.89 [*]	NA	1.10	NA

^{*} Effect sizes correspond to Shewart-chart criteria for significant change in level of performance.