Introduction

Verbal short-term memory (STM) impairments are invariably present in aphasia. Word processing involves activating semantic and phonological representations and maintaining activation over time. Thus, it seems reasonable that impairments of the two abilities might co-occur. Empirical evidence supports a relationship between word processing and STM (see Martin, 2008 for review). Current models of word processing (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997) emphasize a temporal component: maintenance of semantic and phonological representations of words during processing. Martin & Saffran (1997) proposed that impairment of this 'activation maintenance' ability results in deficits of both word processing and verbal STM. Consistent with this view, some researchers have developed treatments to improve verbal STM in aphasia in order to improve both language function and verbal STM (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 generalize to content and tasks beyond those used in treatment. We tested this hypothesis using a treatment for word processing that targeted the ability to access and maintain activation of phonological representations of words in the context of a repetition task that varied memory load.

Methods

Participant. FS, a 55 year old female, experienced a left MCA hemorrhage in November, 2005. She was 28 months post onset when enrolled in our treatment study. She is right-handed, a native speaker of English, and high school educated.

Pretreatment language assessment. Standardized test results are reported in Table 1. FS's aphasia classification on the *Western Aphasia Battery* (Kertesz, 1982) was Conduction Aphasia. Other test results indicated a mild semantic processing deficit and moderate phonological processing deficit. She made phonological errors in repetition and naming and had difficulty rejecting nonwords in an auditory lexical decision task.

FS was administered the *Temple Assessment of Language and Short Term Memory in Aphasia (TALSA*, Martin, Kohen & Kalinyak-Fliszar, in preparation) a comprehensive assessment of language processing abilities that incorporates (1) STM variations of language measures and (2) linguistic variations of span measures. FS's pre-treatment performance on the *TALSA* is reported in Tables 2a, 2b and 3. She demonstrated comparable performance on measures of input phonological and lexical-semantic processing, but phonological processing difficulties were evident on tasks that engaged output processes: nonword repetition, repetition of phonologically-related word pairs, and picture naming. Additionally, FS performed worse on repetition span for nonwords and words of low imageability, span measures that require more phonological than semantic support. These results suggest a primary difficulty in activating and/or maintaining activation of phonological representations of words.

Treatment protocol. FS was enrolled in a treatment program designed to improve ability to activate and maintain activation of word representations. It includes two modules, Phonological and Phonological + Semantic, each with two levels: (1) single words and (2) multiple words. The treatment task is repetition of words, nonwords, word pairs and word triplets that are varied in ways to stimulate semantic and/or phonological processing. The treatment task is conducted under three conditions that vary the interval between stimulus and response: 1-second Unfilled (1-sec UF), 5-second Unfilled (5-sec UF), and 5-second Filled (naming numbers that appear on a computer screen, 5-sec F). The 5-second intervals are intended to improve the ability to maintain

activation of semantic and phonological representations of words without interference (unfilled) and in the context of interference (filled). Stimulus variations at each level are presented hierarchically from easier to more difficult. Treatment is applied at the interval condition designated for the first treatment application followed by treatment to the *same stimuli* at the remaining interval conditions. Then, participants advance to the next module and the application of treatment continues as described above.

Performance on the TALSA battery determines the starting point of treatment and is based on (1) type of language impairment (semantic or phonological), (2) severity (affecting single or multiple word processing) and (3) STM component (interval at which performance falters). FS began treatment with Phonological Module 1 (single word), which includes two- and three-syllable high-imageability words and two- and three-syllable nonwords. She began with three-syllable words and progressed through the remainder of Module 1. She has completed Phonological Module 2 (multiple word stimuli) and is currently undergoing post-testing for that module.

Stimuli. A 320-item pre-test was administered three times in random order at the 1-sec UF interval. Items were selected if they were not repeated accurately on two of three administrations. Twenty items were selected for each variation: ten for training and ten untrained for probing response generalization.

Experimental design. We used a single-subject, multiple baseline-multiple probe design across behaviors to examine acquisition and generalization effects of treatment and to control for effects of repeated exposure to untrained stimuli (McReynolds & Kearns, 1983). Stimuli designated for treatment and for generalization were measured repeatedly during baseline (minimum of 3 baseline probes). Following baseline, a continuous probing schedule was used for trained and untrained stimuli during training phases and a reduced probing schedule during maintenance phases. Treatment occurred three times per week. Probes were conducted immediately prior to treatment sessions. Treatment continued until 80% accuracy was achieved in two consecutive probe sessions or until 12 treatment sessions were completed.

Results.

Acquisition and maintenance. Figure 1 shows the acquisition and maintenance data for treatment of 3-syllable words and 2- and 3-syllable nonwords. FS improved in all stimulus variations at the 1-sec interval and achieved 80% correct on the last probe for 3-syllable words. At the 5-sec UF interval, she achieved criterion for both 3-syllable words and 2-syllable nonwords. Finally at the 5-sec F interval, she achieved criterion for 3-syllable words. In the case of 2-syllable nonwords, she achieved 80% and 90% accuracy on two probes, but not consecutively.

Effect sizes. Table 4 shows effect sizes for treatment and maintenance phases of training in Phonological Module 1. In the 1-sec UF and 5-sec UF interval conditions, they are quite impressive for both treatment and maintenance phases and especially for the nonword stimuli.

Pre- and post-treatment assessments. Post-treatment data for Module 1 are shown in Tables 1 through 3. FS's performance on standardized tests either improved or was maintained on all measures. The most interesting gains on the *TALSA* battery occurred on the rhyming and synonymy triplet judgments, word pair repetition, and span tasks, which vary memory load in different ways from the treatment task. Accuracy of word pair repetition increased in all three interval conditions (from .10 to .50). This post-test was administered *before* FS began training in Phonological Module 2, which uses word pairs as stimuli. Thus, training on single words after an

interval improved repetition of word pairs. Finally, FS demonstrated increases in span on eight of eleven span tasks.

Discussion.

The results indicate that treatment using one means of increasing STM load (the temporal interval manipulation) improved performance on tasks using another means to increase STM load (number of items in working memory). Thus, we can infer that the treatment improved a fundamental ability to maintain activation of representations in the course of processing words. This processing approach to aphasia therapy is promising because it can be integrated into standard therapy techniques for treatment of language disorders in aphasia.

Acknowledgments.
This research was supported by a grant from the National Institutes of Health awarded to Temple University, Deafness and other Communication Disorders, Grant R21 DC 008782-01 (N. Martin, PI). We are very grateful to the participants who cheerfully and patiently participated in this study. Thanks go to Rebecca Afman, Drew Tipton, Beth Levitan, Ferenc Bunta, and Whitney Postman for collection and recording of data and for all their helpful comments.

References.

Dell, G.S., Schwartz, M.F., Martin, N., Saffran, E.M. and Gagnon, D.A. (1997). Lexical access in aphasic and non-aphasic speakers. *Psychological Review*, 104 (4), 801-838.

Kertesz, A. (1982). *Western Aphasia Battery*. The Psychological Corporation, Harcourt Brace Jovanovich, Inc.

Koenig-Bruhin, M. & Studer-Eichenberger, F. (2007) Therapy of verbal short-term memory disorders in fluent aphasia: A single case study. *Aphasiology*, 21(5) 448-458.

Martin, N. (2008). The role of semantic processing in short-term memory and learning: Evidence from Aphasia. In A. Thorn & M. Page (Eds.) *Interactions between short-term and long-term memory in the verbal domain.* Psychology Press, Chapter 11, pp. 220-243.

Martin, N., Kohen, F. & Kalinyak-Fliszar. (in preparation). A diagnostic battery to assess language and short-term memory deficits in aphasia.

Martin, N. & Saffran, E.M. (1997).Language and auditory-verbal short-term memory impairments: Evidence for common underlying processes. *Cognitive Neuropsychology*, 14 (5), 641-682.

McReynolds, L. V. & Kearns, K. P. (1983). *Single–Subject experimental Design in Communication Disorders*, Baltimore , MD: University Park Press.

Table 1

Pretreatment assessment

MEASURE	*Pretreatment*	*Post treatment*
Western Aphasia Battery		
Information content	9/10	9/10
Fluency	6/10	9/10
Comprehension		
Yes/no questions	45/60	60/60
Auditory word recognition	53/60	56/60
Sequential commands	41/80	70/80
Repetition	50/100	69/100
Naming		
Object naming	53/60	57/60
Word fluency	11/20	12/20
Sentence completion	10/10	10/10
Responsive speech	10/10	10/10
Aphasia Quotient	70.6	85.5
Aphasia Classification	Conduction	Conduction
Boston Naming Test	32/60	NA
Philadelphia Repetition Test (n=175)		
1-syllable	77/100	88/100
2-syllable	33/52	44/52
3- and 4-syllable	10/23	15/23
Peabody Picture Vocabulary Test IIIA		
Raw Score	129	134
Standard Score	66	NA
Pyramid and Palm Trees		
Picture	45/52	48/52
Word	46/52	44/52
Auditory Lexical Decision		
Words	30/40	38/40
Nonwords	26/40	25/40

Table 2

Part 1. Single and multiple word processing tasks with STM variations

A. STM variation 1: 3 interval conditions (between stimuli or before a response)

	Pretreatment			Post treatment		
Input phonological and lexical-semantic tasks	**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 judgments						
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 judgments (n=20)	0.90	0.90	0.65	1.00	1.00	0.95
Sentence comprehension (n=19)	0.79	0.68	0.68	0.68	0.63	0.79
Single word processing tasks that engage output processes	**Interval Condition**			**Interval Condition**		
	1-sec UF	5-sec UF	5-sec F	1-sec UF	5-sec UF	5-sec F
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
Picture naming (n=30)	0.80	0.80	0.80	0.87	0.90	0.93
Multiple word utterances with interval conditions	**Interval Condition**			**Interval Condition**		
	1-sec UF	5-sec UF	5-sec F	1-sec UF	5-sec UF	5-sec F
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
Sentence repetition						
Unpadded (n=50)	0.62	0.56	0.54	0.60	0.64	0.46
Padded (n=80) / Post Tx (n=70)	0.36	0.30	0.30	0.41	0.41	0.39

Table 2
Part 1.

B. STM variation 2: Increasing memory load on word judgment tasks

	Pretreatment		Post treatment	
	2-item version	**3-item version**	**2-item version**	**3-item version**
Synonymy Triplet Judgments (n=40)*	0.85	0.73	0.93	0.93
Rhyming Triplet Judgments (n=30)**	0.87	0.76	0.97	0.77

*Item words
**Item pictures

Table 3

Part 2. Span measures with language variations

	Pretreatment	Post treatment
Digit and Word 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)

Table 4

FS Phonological Therapy Effect Sizes (Calculated from Original Baseline)

	1 sec unfilled			5 sec unfilled			5 sec filled		
	3-syllable words	**2-syllable nowords**	**3-syllable nonwords**	**3-syllable words**	**2-syllable nowords**	**3-syllable nonwords**	**3-syllable words**	**2-syllable nowords**	**3-syllable nonwords**
Treatment Effect Sizes									
Treated items	2.55	7.34	4.68	5.21	15.05	7.34	6.44	13.20	11.30
Generalization items	0.26	5.10	4.07	0.14	5.29	2.85	0.16	3.68	5.95
Maintenance Effect Sizes									
Treated items	1.49	6.93	N/A	4.84	15.46	N/A	7.11	19.12	N/A
Generalization items	0.13	7.73	N/A	-0.09	2.05	N/A	0.22	5.30	N/A

Figure 1. FS phonological module 1: Single words and nonwords