INTRODUCTION

Working memory (WM) is the cognitive system that functions for the temporary storage, activation, and manipulation of information in support of complex, goal-directed behavior (Baddeley, 2003; Kane, Conway, Hambrick, & Engle, 2007). This system is limited in capacity, and it includes an attentional or central executive component that serves to block interference, resolve conflict, and flexibly manage its capacity limitations (Baddeley, 2003; Just & Carpenter, 1992; Kane et al., 2007). It has been suggested that WM deficits may contribute to language performance impairments in aphasia (Caspari, Parkinson, LaPointe, & Katz, 1998; Friedmann & Gvion, 2003; Wright, Downey, Gravier, Love, & Shapiro, 2007; Wright & Shisler, 2005). Accordingly, clinical researchers have begun to study whether aphasia treatment targeted at WM or related processes may be efficacious.

Vallat et al. (2005) administered WM treatment tasks to an aphasic patient with specific impairments in verbal WM, and observed significant improvements in verbal WM and central executive functioning, and nonsignificant improvements in reading comprehension. Martin et al. (2009) and Kalinyak-Fliszar, Kohen, and Martin (2011) used sentence repetition tasks with filled and unfilled delays between stimulus and response to improve short term memory (STM) for phonological and lexical-semantic representations. Participants with Wernicke's and conduction aphasia improved on repetition tasks, span tasks, and standardized comprehension assessments. Francis, Clark, and Humphreys (2003) studied a patient with mild aphasia and comprehension deficits. They implemented a sentence repetition task to address STM/WM deficits hypothesized to be the main cause of the patient's comprehension impairments. Improvements in auditory memory tasks were noted with limited improvement in comprehension. Mayer and Murray (2002) used a word span task and an adapted text-level reading approach to improve comprehension in a patient with mild aphasia and alexia. While both programs increased reading rate, neither affected reading comprehension.

The purpose of this study was to evaluate the efficacy of a WM treatment based on an auditory sentence span task theoretically targeted at central executive functioning for improving the WM span and auditory comprehension performance of a person with moderate aphasia.

METHOD

Participant: K.D. is a 58 year-old right-handed female 25 months post-onset (MPO) of LMCA occlusion with aphasia and mild unilateral upper motor neuron dysarthria.

Pre-Treatment Assessments: A comprehensive battery of language assessments was administered at 18 and 25 MPO (Table 1), demonstrating moderate aphasia with impairments across all modalities.

K.D. had conceptual and lexical-semantic impairments, based on her relatively poor performance on the Pyramids and Palm Trees, semantic errors on word-to-picture matching and oral reading, and frequent semantic paraphasias on confrontation naming. We also hypothesized a WM deficit, based on her poor performance on complex span tasks relative to simple repetition and forward span tasks, and on the discrepancy between her auditory comprehension of single words and sentences at initial testing. Also, there was a prominent length effect on her sentence comprehension.

Treatment: Given K.D.'s apparent WM deficits, we implemented a treatment (Table 2) based on an auditory sentence span task (Tompkins, Bloise, Timko, & Baumgaertner, 1994). This protocol was

administered in the context of an intensive four-week residential aphasia program during which she received 80 hours of treatment. Following the baseline phase, the WM treatment was administered for 60-65 minutes/day across 12 consecutive treatment days for a total of 12.5 hours. K.D. also received treatment with Verb Network Strengthening Treatment (VNeST, Edmonds & Babb, 2009) (24.7 total hours), Copy and Recall + Repetition writing treatment (CART+R, Beeson & Egnor, 2006) (13.5 hours), Script Training (Cherney, Halper, Holland, & Cole, 2008) (4.8 hours), impairment-focused group treatment (10 hours), and life participation group treatment (15.1 hours).

Experimental Design: The WM treatment was administered in a multiple baseline across behaviors design including three phases: baseline (7 observations), treatment (12 observations), and follow-up (1 observation), with daily probes of trained and untrained sentence span stimuli, auditory sentence-to-picture matching, and an adjective synonym retrieval task. The sentence-to-picture matching task was included to assess generalization to auditory comprehension. The synonym retrieval task was included as a control to assess for non-specific treatment effects. Treatment with VNeST, CART+R, and Script Training was initiated in the first week after 3 baseline probes were collected across 2 days. Weekly probes of sentence production, writing to dictation, and picture naming were also administered to assess the effects of VNeST and CART+R.

Stimuli: The WM treatment and probe stimuli consisted of 168 simple active declarative sentences of 3-5 words in length, each ending in a different 1-2 syllable word. Forty-two of these sentences were taken from Tompkins et al. (1994), and the rest were developed to parallel those sentences. Half of the sentences were designated as treatment stimuli and half were designated as untreated probe items. During each daily treatment session, sentences were sampled randomly from the treatment set. For the treated and untreated probes, a different random sample of 42 sentences was taken from each set for each probe session. The sentences were presented in ascending sets of 2-5 sentences, with three sets at each level.

The auditory sentence comprehension probes were taken from the PALPA Sentence-Picture matching subtest. The 60 sentences were organized into two 30-item sets. Stimulus order and target/foil placement were permuted to create three forms of both sets. The same form was never administered during consecutive sessions.

The adjective synonym control probes consisted of 15 adjectives with frequently occurring synonyms.

The VNeST verb stimuli were taken from Edmonds & Babb (2009). The CART+R stimuli were generated by K.D. and her daughter.

RESULTS

The primary dependent variables were the number of correct sentence-final words recalled in the sentence span probes and the number of correct sentence-picture matching responses. We also examined pre/post performance on other measures of WM and general language functioning, as well as weekly probes related to the other treatments.

Figure 1 presents the data for the treated and untreated sentence span, sentence-picture matching, and synonym retrieval tasks. Analysis using the Tau-U statistic (Parker, Vannest, Davis, & Sauber, 2011), a combined measure of non-overlap and trend, suggested that there were significant effects of treatment on trained recall (Tau-U=0.60, $p<0.001$), trained plausibility judgments (Tau-U=0.57, $p=0.04$), untrained

recall (Tau-U=0.67, p<0.001), and sentence-picture matching (Tau-U=0.39, p=0.03). There were no significant effects on untrained plausibility judgments (Tau-U=-0.21,p=0.46) or the synonym control task (Tau-U=0.19, p=0.51). We also computed effect sizes comparing performance at follow-up to performance at baseline. All effect sizes were small or negative, suggesting that gains were not maintained. Also, as shown in Table 1, there was minimal improvement on other complex WM span tasks.

Weekly probes related to the VNeST and CART+R treatments are presented in Figure 2. Visual inspection suggested positive effects of both treatments, with robust generalization to untreated items for VNeST.

With respect to general language performance, the CAT, the PICA, and a story retell task showed modest overall increases.

DISCUSSION

We found significant but modestly-sized positive effects of the WM treatment on sentence span and sentence comprehension performance, but these gains were not maintained at follow-up, nor did they generalize to other measures of WM span. There were small gains in overall comprehension performance, again with questionable maintenance at follow-up. Comparison of our results with prior studies suggests that treatment with multiple tasks targeting different components of WM may be necessary to achieve positive results.

References

Baddeley, A. (2003). Working memory and language: an overview. J Commun.Disord., 36, 189-208.

Beeson, P. M. & Egnor, H. (2006). Combining treatment for written and spoken naming. Journal of the International Neuropsychological Society, 12, 816-827.

Caspari, I., Parkinson, S. R., LaPointe, L. L., & Katz, R. C. (1998). Working memory and aphasia. Brain and Cognition, 37, 205-223.

Cherney, L. R., Halper, A. S., Holland, A. L., & Cole, R. (2008). Computerized script training for Aphasia: Preliminary results. American Journal of Speech-Language Pathology, 17, 19-34.

Edmonds, L. & Babb, M. (2009). Effect of verb network strengthening treatment (VNeST) in moderate-severe aphasia. American Journal of Speech-Language Pathology, 1-41.

Francis, D. R., Clark, N., & Humphreys, G. W. (2003). The treatment of an auditory working memory deficit and the implications for sentence comprehension abilities in mild "receptive" aphasia. Aphasiology, 17, 723-750.

Friedmann, N. & Gvion, A. (2003). Sentence comprehension and working memory limitation in aphasia: A dissociation between semantic-syntactic and phonological reactivation. Brain and Language, 86, 23-39.

Just, M. A. & Carpenter, P. A. (1992). A capacity theory of comprehension: individual differences in working memory. Psychological Review, 99, 122-149.

Kalinyak-Fliszar, M., Kohen, F., & Martin, N. (2011). Remediation of language processing in aphasia: Improving activation and maintenance of linguistic representations in (verbal) short-term memory. Aphasiology, 25, 1095-1131.

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., & Engle, R. W. (2007). Variation in working memory capacity as variation in executive attention and control. In A.R.A.Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), Variation in Working Memory (pp. 21-48). New York: Oxford University Press.

Martin, N., Kohen, F., McCluskey, M., Kalinyak-Fliszar, M., & Gruberg, N. (5-26-2009). Treatment of a language activation maintenance deficit in Wernicke's aphasia. Presented to the 39th annual Clinical Aphasiology Conference, Keystone, CO.

Mayer, J. F. & Murray, L. L. (2002). Approaches to the treatment of alexia in chronic aphasia. Aphasiology, 16, 727-743.

McNeil, M. R., Doyle, P. J., Fossett, T. R. D., Park, G. H., & Goda, A. J. (2001). Reliability and concurrent validity of the information unit scoring metric for the story retelling procedure. Aphasiology, 15, 991-1006.

Parker, R. I., Vannest, K. J., Davis, J. L., & Sauber, S. B. (2011). Combining nonoverlap and trend for single-case research: Tau-U. Behav.Ther., 42, 284-299.

Tompkins, C. A., Bloise, C. G. R., Timko, M. L., & Baumgaertner, A. (1994). Working memory and inference revision in brain-damaged and normally aging adults. Journal of Speech and Hearing Research, 37, 896-912.

Vallat, C., Azouvi, P., Hardisson, H., Meffert, R., Tessier, C., & Pradat-Diehl, P. (2005). Rehabilitation of verbal working memory after left hemisphere stroke. Brain Injury, 19, 1157-1164.

Wright, H. H., Downey, R. A., Gravier, M., Love, T., & Shapiro, L. P. (2007). Processing distinct linguistic information types in working memory in aphasia. Aphasiology, 21, 802-813.

Wright, H. H. & Shisler, R. J. (2005). Working memory in aphasia: theory, measures, and clinical implications. American Journal of Speech-Language Pathology, 14, 107-118.

Table 1. Language and communication assessment results.

	Pre-Tx 1 (7 mos. prior to program entry)	Pre-Tx 2 (program entry)	Post-Tx 1 (program exit)	Post-Tx 2 (1-mo. follow-up)
The Comprehensive Aphasia Test (CAT)				
Mean Modality T-Score	47.25	48.75	51.25	50.25
Comprehension of Spoken Language	42	47	52	47
Comprehension of Written Language	43	45	47	46
Repetition	53	54	58	58
Naming	46	49	50	50
Spoken Picture Description	47	48	50	49
Reading	46	46	49	48
Writing	47	47	50	50
Written Picture Description	54	54	54	54
Porch Index of Communicative Ability				
Overall %ile	51	52	54	
Verbal %ile	51	53	54	
Auditory Comp %ile	31	35	32	
Reading %ile	35	35	42	
Writing %ile	60	61	59	
Pyramids and Palm Trees				
3-Picture Version	81% (42/52)			
Pyscholinguistic Assessment of Language Processing in Aphasia				
Same-Different Discrimination Word Minimal Pairs	100% (30/30)			
Same-Different Discrimination Non-Word Minimal Pairs	95% (38/40)			
Imageability & Frequency Auditory Lexical Decision	97.5% (39/40)			
Phonological Segmentation of Initial Sounds	60% (18/30)			
Letter Naming	30.7% (8/26)			
Letter Sounding (grapheme-to-phoneme)	8.0% (2/25)			
Spoken Letter-Written Letter Matching	64% (16/25)			
Imageability & Frequency Reading	56% (22/39)			
Auditory Digit Span Matching	6			

	Pre-Tx 1 (7 mos. prior to program entry)	Pre-Tx 2 (program entry)	Post-Tx 1 (program exit)	Post-Tx 2 (1-mo. follow-up)
Digit Repetition Span	4			
McNeil Story Retell Procedure (McNeil, Doyle, Fossett, Park, & Goda, 2001)				
% Information Units	3.8	6.3	11.8	
Burden of Stroke Scale (higher scores denote greater burden / poorer functioning, max = 100)				
Cognitive Composite	63.24	48.53		54.41
Psych Distress Composite	41.91	22.06		4.41
Communication	64.29	64.29		64.29
Cognition	45	55		70
Social Relationships	80	20		25
Working Memory Span Tasks				
Backward Digit Span		2	3	2
Subtract 2 Span		< 2	2	< 2
Alphabet Span		2	2	< 2

Table 2. Working Memory Treatment Protocol

1	Beginning with a sentence set size of 2, treatment stimuli were presented as in a typical sentence span task with the following instructions: "Listen carefully. You will hear some sentences. After you hear each sentence, state 'yes' if the sentence is TRUE or COULD happen and 'no' if the sentence is FALSE or COULD NOT happen. Listen to each sentence and remember the FINAL word of each sentence. You will be asked to recall the FINAL words following each set of sentences."
2	Patient made a plausibility judgment after each sentence and then, after each set, attempted to recall the final word of each sentence.
3	If spontaneous recall was incorrect, then written choices for recognition were presented on index cards with the following protocol: a. Number of foils=2N (ie. if patient is working at the two word level, then the two correct final words and four foils were presented) b. Verbal reinforcement pertaining to accuracy was given after each selection c. Foils were words of other trained sentences
4	For inaccurate multiple choice responses, the clinician read the corresponding sentences aloud and identified the final word by pointing to the appropriate index card`
5	Written stimuli were provided to the patient and read aloud to review plausibility judgments for all stimuli regardless of accuracy. Supportive communication was used as needed.
6	The sentence set size was increased by one when probe plausibility judgments and word recall at the current treatment set size were both ≥80% across two out of three daily probe sessions.

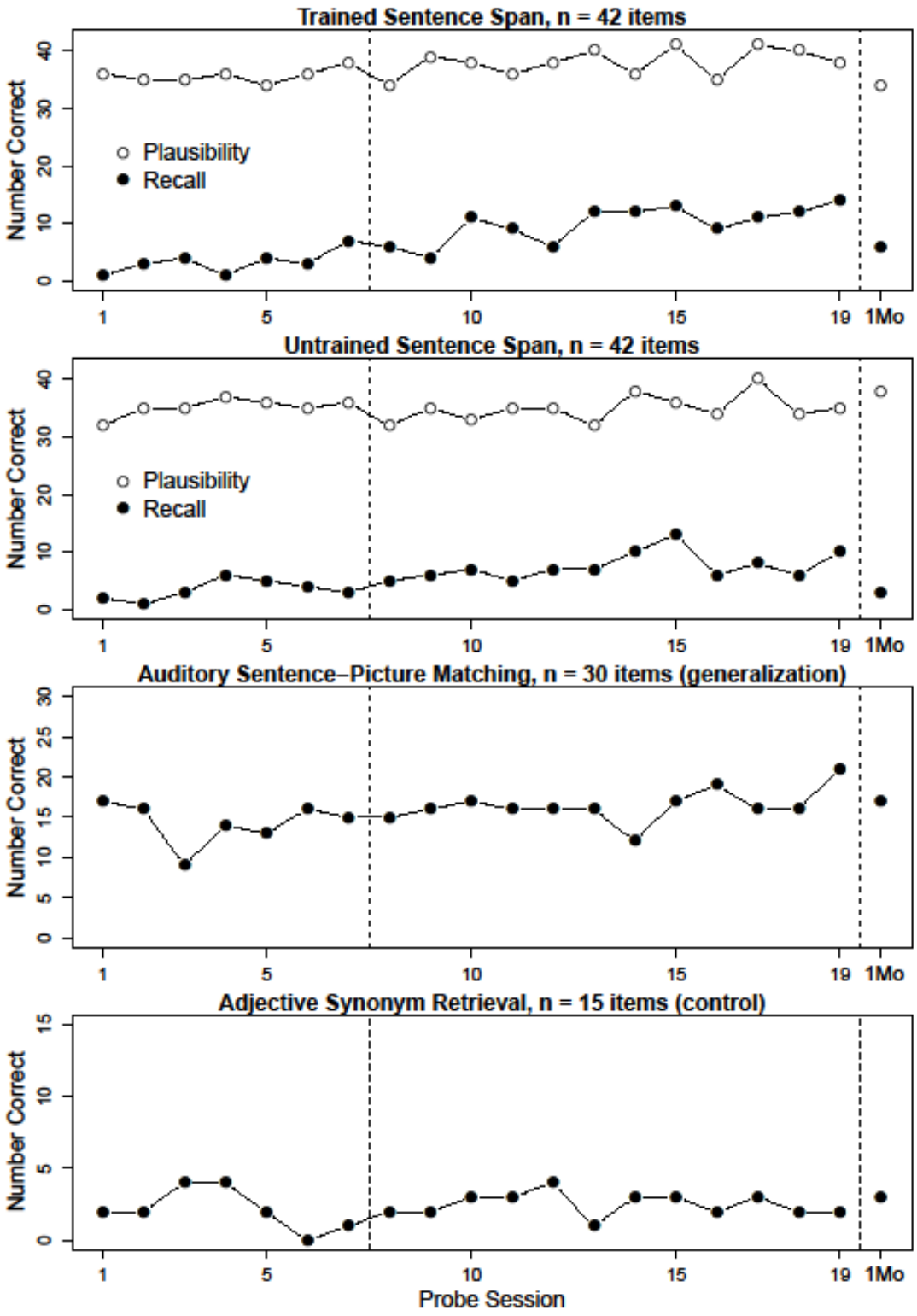

Figure 1. Number of correct probe responses for sentence span, auditory comprehension, and synonym retrieval control probes. The dashed vertical lines indicate the beginning and end of the working memory treatment.

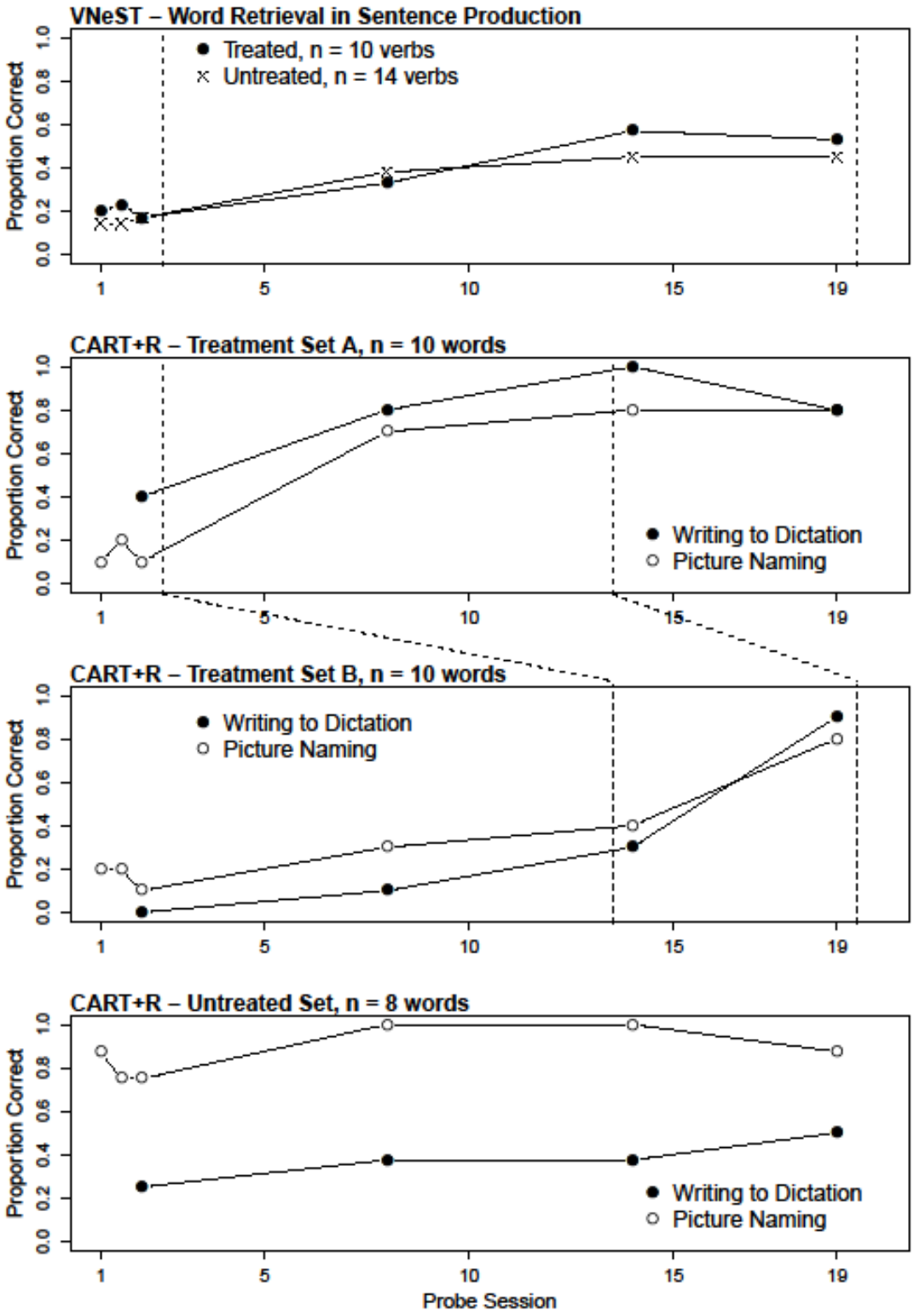

Figure 2. Proportion of correct probe responses for VNeST and CART+R probes. The dashed vertical lines within each plot indicate the beginning and end of treatment for those items.