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Short-Term Memory and Aphasia: From Theory to Treatment

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Abstract

This article reviews existing research on the interactions between verbal short-term memory and language processing impairments in aphasia. Theoretical models of short-term memory are reviewed, starting with a model assuming a separation between short-term memory and language, and progressing to models that view verbal short-term memory as a cognitive requirement of language processing. The review highlights a verbal short-term memory model derived from an interactive activation model of word retrieval. This model holds that verbal short-term memory encompasses the temporary activation of linguistic knowledge (e.g., semantic, lexical, and phonological features) during language production and comprehension tasks. Empirical evidence supporting this model, which views short-term memory in the context of the processes it subserves, is outlined. Studies that use a classic measure of verbal short-term memory (i.e., number of words/digits correctly recalled in immediate serial recall) as well as those that use more intricate measures (e.g., serial position effects in immediate serial recall) are discussed. Treatment research that uses verbal short-term memory tasks in an attempt to improve language processing is then summarized, with a particular focus on word retrieval. A discussion of the limitations of current research and possible future directions concludes the review.

Keywords

Aphasia rehabilitation; verbal short-term memory; interactive activation; language assessment

CONTRIBUTIONS OF SHORT-TERM MEMORY TO LANGUAGE PROCESSING

A paradigm shift is occurring in the field of aphasiology: Researchers are moving away from talking about cognition *and* language to talking about the cognitive requirements *of* language processing. Such a shift is consistent with a prior move away from the idea that aphasia is a problem of representational loss and toward the view that aphasia is a problem of access to linguistic representations. In the context of an access view, it is imperative to study processes

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that facilitate access to linguistic representations to better understand how to treat the disorder. One cognitive process at the forefront of research in the field of aphasiology is verbal short-term memory (STM), the temporary, limited-capacity storage of linguistic information. Classically, verbal STM has been experimentally and clinically tested by auditorily presenting a sequence of digits or words and having the participant or client repeat them immediately after their presentation (i.e., immediate serial recall), a method that continues to be the most widespread in the recent literature.¹ STM can be thought of as a subset of working memory, which encompasses both this fleeting information storage system and other attentional functions that allow longer maintenance of information in STM and more active manipulation of the stored information.^{2,3} Verbal STM is almost ubiquitously found to be impaired in individuals with aphasia,² and thus, understanding the interaction between verbal STM and language processing is a theoretically and clinically important endeavor. The contribution of verbal STM research to the theoretical and clinical understanding of aphasia is the focus of this article, whereas attentional contributions are discussed in a separate article in this issue.

Classic models of STM view language and STM as separable processes.^{4,5} Baddeley and Hitch,⁵ who developed the classic model of working memory, assumed that a phonological code supported the recall of an auditorily presented list of numbers and words, but was not directly connected to the phonological processing required to produce and comprehend language. According to the model, a list of items is temporarily stored in verbal STM via a predominately phonological code, an idea supported by a series of behavioral phenomena observed in empirical studies of verbal STM in typical speakers. These include the *phonological similarity effect*, referring to the finding that phonologically similar items are more difficult to recall in a sequence than less similar ones,^{6,7} and *the word length effect*, describing the finding that shorter words (i.e., words with fewer phonemes) are more likely to be correctly recalled than longer words. The word length effect has since been challenged in the literature with subsequent studies that failed to recreate the effect, and others that demonstrated that the word length effect may be confounded by orthographic properties of target words (for review, see Caplan et al⁸). Additionally, although the phonological similarity effect demonstrates the existence of one type of coding in verbal STM (i.e., sound based), the fact that other lexical-semantic properties such as imageability, frequency, and concreteness have repeatedly been shown to affect verbal STM performance suggests that there is much more to the story.^{9–13} Although a semantic component (i.e., the episodic buffer) was later added to the working memory model to account for the influence of meaning on immediate serial recall performance,¹⁴ the processing assumptions of the episodic buffer are quite vague, and the revised model makes no direct connection between semantic influences in verbal STM and the semantic processing required for language processing.

In contrast to the classic view that posits separable verbal STM and language processes, Martin and Saffran argued that STM is largely a property of the process it supports, meaning that to understand the connection between STM and language, we must carefully consider the temporary storage requirements of language processing itself.¹⁵ The authors framed their model from the perspective of Dell's interactive activation (IA) model of language processing.^{16,17} The IA model posits that word retrieval requires (1) a lexical access stage,

during which activated semantic concepts send activation to corresponding lexical (i.e., word) representations, and the most highly activated lexical item is selected, and (2) a phonological access stage, during which lexical representations send activation to phonological representations and sounds corresponding to the chosen lexical item are selected. The linguistic levels described in the model (i.e., semantic, lexical, and phonological) are connected bidirectionally, meaning that activation of later representational levels influences earlier levels of processing. Thus, prior to initiation of step 2 (selection of phonemic representations of an intended utterance), activation spreads from primed lexical nodes to their phonological representations in step 1, and these primed phoneme representations feed activation back to lexical nodes, thus influencing the probabilities of a word being selected in step 1.

At each step of the process, linguistic representations begin to decay toward baseline activation levels immediately after they are activated. If nodes of the target word decay too quickly or activation between representational levels is weak, a more highly activated related (e.g., semantic or phonological) or unrelated word or nonword may be selected instead, or an omission (i.e., nonresponse) can occur. Martin and Saffran argued that verbal STM is largely, though not completely, encompassed in this temporary linguistic activation process underlying language production (and, in reverse order, language comprehension, which begins with phonological activation and proceeds to lexical-semantic activation).¹⁵ Martin and Saffran's model deviates from Baddeley and Hitch's classic model in two ways: (1) the model assumes that verbal STM is an inherent property of language processing and, by extension, that (2) lexical-semantic representations are key players in the verbal STM process.⁵

The linguistically based IA theory of verbal STM is consistent with Cowan's more general embedded processes STM model,¹⁸ which posits that STM representations are made up of temporarily activated knowledge from long-term memory, and that the code through which temporary activation functions (e.g., semantic, tactile, visuospatial) depends on the task that the temporarily activated knowledge supports. In the case of the production of the word *cat*, for example, semantic (e.g., meows, has four legs), lexical, and phonological representations from long-term memory are temporarily activated in STM until their corresponding word is retrieved. The assertion that verbal STM representations constitute temporarily activated linguistic long-term memory knowledge is consistent with neural evidence that links STM impairment (as measured by immediate serial recall of digits) and language processing impairments (as measured by classic language tasks such as naming and sentence comprehension) to damage of common neural regions (for review, see Cahana-Amitay and Albert¹⁹). Together, the models and empirical evidence discussed previously suggest that we must consider the STM requirements of language processing, rather than viewing STM as a cognitive process that is related to but separable from the language system.

EXPECTED LANGUAGE DEFICITS RESULTING FROM VERBAL SHORT-TERM MEMORY IMPAIRMENT

A strong relationship between verbal STM ability and language impairment has been established in a series of studies, which demonstrate that an individual's ability to recall a list of digits or words (i.e., the number of digits/words they can recall) is directly and positively correlated with their performance on classic language production and comprehension tasks.^{20–22} Additionally, individuals with aphasia demonstrate lower immediate serial recall span performance (i.e., fewer digits/words correctly recalled) than individuals with left hemisphere damage without concomitant aphasia and individuals with right hemisphere damage without concomitant aphasia,^{23,24} suggesting that the reduced verbal STM capacity (as measured by immediate serial recall span length) is not simply due to generalized slowed processing that might be expected in brain-damaged individuals.

Studies that move beyond identifying reductions in verbal STM span length as a critical marker of STM impairment attempt to link the type of deficits seen in the verbal STM system with the type of linguistic deficits seen in aphasia (i.e., predominately semantic processing deficit versus predominately phonological processing deficit). Such studies are important because, although measures of verbal STM span length in aphasia can predict the severity of an individual's language impairment, they do not identify the type of language impairment that is present, which is critical for the implementation of sensitive and specific treatment protocols. Martin and Saffran attempted to link verbal STM impairment to receptive language impairment type in 15 individuals with aphasia and impaired digit and word span length performance.¹⁵ The participants were given a battery of semantic (i.e., word to picture matching, synonymy judgments) and phonological (i.e., minimal pair judgments, rhyme judgments) tasks, and a relative impairment semantic-phonological (S-P) score was derived from their performance on these tasks, with individuals who demonstrated stronger semantic processing receiving positive scores and those with stronger phonological processing receiving negative scores. Additionally, participants completed a verbal STM task that required them to repeat pairs of words spoken at a rate of 1 second per word in the order in which they were presented. The authors predicted that individuals who were stronger semantically (i.e., those with positive S-P scores) would show better recall for the first word than the second word (*primacy bias*), whereas individuals who were stronger phonologically would show better recall for the second over the first word (*recency bias*). Predictions were framed in the context of Dell's IA model of language processing¹⁶: at the time of recall in the verbal STM task, activation of the first presented word has more time to spread from the phonological to the semantic level than the activation of the second word, simply because the first word is presented a second earlier. Short-term storage of the first word, then, should be more strongly subserved by activation of semantic-level representations, whereas short-term storage of the second word should be more strongly subserved by activation of phonological-level representations. Additionally, the authors predicted that individuals with relatively stronger receptive semantic processing (i.e., positive S-P scores) would demonstrate better recall of high imageability words relative to low imageability words, whereas individuals with relatively stronger phonological processing should not be as susceptible to these manipulations, a prediction rooted in the

idea that high imageability words have richer semantic representations, and are thus easier to activate at the semantic level of processing than low imageability words.^{25,26}

The predictions were realized: as S-P scores increased, primacy and imageability biases also increased. These findings provided strong evidence for a linguistic account of STM, which, at least in part, defines verbal STM as temporary activation of linguistic representations necessary for the completion of specific language tasks. These findings were more recently replicated in three-word strings,^{27,28} demonstrating that positional biases in verbal STM tasks can potentially inform the extent to which an individual's language impairment is semantically or phonologically driven, and thus help delineate what tasks to focus on in treatment to optimize language comprehension improvement. The fact that significant associations have been found between language impairment type and the recall of both two- and three-word strings suggests the importance of examining positional biases with multiple word string lengths. For example, an individual may perform at ceiling and not show a positional bias for immediate serial recall of two-word strings but may show a bias for recall of three- and/or four-word strings. Overall, the move beyond the measurement of verbal STM with immediate serial recall span length to other more intricate components such as positional and imageability biases in immediate serial recall helps inform the diagnosis and treatment of receptive language impairments in aphasia.

What do we know about whether and how more intricate measures of verbal STM performance inform word retrieval, the most pervasive impairment in aphasia?²⁹ Wilshire et al conducted a case study of two individuals with aphasia and demonstrated associations between verbal STM and word-retrieval impairment that mirrored those found with receptive language impairment.³⁰ One individual made predominately phonological errors in picture naming (i.e., relatively stronger semantic processing) and demonstrated primacy and imageability biases in immediate serial recall, whereas a second individual made predominately semantic errors in picture naming (i.e., relatively stronger phonological processing) and demonstrated a recency bias and no imageability bias. In a related case study, Verhaegen and colleagues administered a phonological and a semantic verbal STM task to two individuals with aphasia, one who demonstrated mostly semantic naming errors and improved performance when phonemic cues were provided, and another who made mostly phonological naming errors and demonstrated no benefit with phonemic cueing.³¹ The phonological STM task involved listening to a list of words and determining whether a probe word rhymed with any words on the list, whereas the semantic task involved listening to a list of words and determining whether a probe word was semantically related to any words on the list. The individual with a predominately phonological naming impairment demonstrated impaired performance on the phonological STM task and nonimpaired performance on the semantic STM task, whereas the individual with a predominately lexical-semantic naming impairment demonstrated the opposite profile. These case studies, although small in scale, support a linguistically dominant view of verbal STM.

In a larger study of 24 individuals with aphasia and verbal STM impairment (as defined by impaired immediate serial word recall span length), Minkina et al investigated links between word retrieval impairment type (predominately semantically driven versus predominately phonologically driven impairment) and intricate measures of verbal STM (positional and

imageability biases, as explored by Martin and Saffran).^{15,32,33} To characterize word retrieval impairment type, the Philadelphia Naming Test (a 175-item picture naming test with items varied for syllable length and frequency) was administered, and naming errors were coded according to the test's guidelines.³⁴ A relative impairment phonological-semantic (P-S) score was calculated for each participant by subtracting the number of semantically related errors from the number of phonologically related nonword errors, with individuals who demonstrated relatively greater phonological naming impairments receiving positive scores and those who demonstrated relatively greater semantic naming impairments receiving negative scores. The participants also performed a word pair repetition verbal STM task. The authors found that as P-S scores increased, imageability bias (i.e., bias toward correct responses on high imageability words) on the verbal STM task increased, consistent with the findings of Martin and Saffran for receptive language impairment.¹⁵ The parallel result for word retrieval data in relation to verbal STM lends further support to a linguistically centered view of verbal STM. Importantly, however, when links between positional (i.e., primacy/recency) biases in verbal STM and word retrieval impairment type (as measured by P-S score) were examined, no significant findings emerged, a result that contrasts with extant findings for receptive language impairment. This discrepancy may be due to the different verbal STM requirements of the receptive language tasks, where a fleeting auditory stimulus must quickly be processed, from that of a classic picture naming task, where participants are given ample (in this case, 30 seconds) time to respond. In a more ecologically valid word retrieval task, where response time is limited and the verbal STM burden is thus increased, a link between word retrieval impairment type and verbal STM may possibly have been found.

Together, the work summarized previously supports an interactive linguistic activation view of verbal STM. In an alternative account, Attout and colleagues proposed that the STM mechanism for item information (e.g., words and digits) is linguistically specified, whereas serial order information is subserved by a separate STM mechanism.³⁵ In a case study of two individuals with a history of aphasia, they reported on one individual with aphasia characterized by phonological processing impairments and a second individual who initially presented with anomia, but demonstrated within normal limits performance on classic language tests (e.g., picture naming, word reading, nonword repetition). The first individual demonstrated impaired item (digit and word) STM in immediate serial recall but demonstrated order recall ability within normal limits when he was presented with a list of words succeeded by two probe words and had to indicate the order the probes appeared in the list. Conversely, the second individual, who scored within normal limits on classic language tests, demonstrated preserved item STM and impaired order STM. Based on these results, the authors proposed that STM for item information is linguistically dependent, whereas STM for order information is subserved by a separate mechanism. An important caveat to their conclusions, aside from the small sample size, is that although the individual who exhibited impaired order in recall was said to have no residual language deficits, he reported difficulty with following conversations and reading for long periods of time.

In a follow-up study with a larger number of participants diagnosed with fluent aphasia ($n = 14$), Majerus and colleagues demonstrated a variety of different verbal STM profiles, with some individuals showing both item and order STM deficits ($n = 2$), some showing deficits

either in item ($n = 1$) or order ($n = 4$) STM, and others showing weak but unimpaired item and order verbal STM performance (relative to neurologically healthy control participants).³⁶ The authors concluded that the results were inconsistent with a predominately linguistic view of verbal STM. Importantly, the individuals included in this study were very mild, with digit spans between four and six items. Additionally, the authors reported that when neurologically healthy controls were given tests of item and order verbal STM, imageability affected both item and order performance, suggesting that order STM cannot be deemed to be completely nonlinguistic. Regardless of these caveats, these studies demonstrate the importance of examining both item and order verbal STM performances in individuals with aphasia to more accurately diagnose language impairments.

Collectively, the literature supports the existence of a linguistically driven verbal STM mechanism, but cautions that additional verbal STM mechanisms may also support classic verbal STM task performance. Though verbal STM treatment studies conducted with individuals with aphasia are scarce in the literature, the existing ones have mostly embraced the idea that STM impairments in aphasia must be treated in a linguistic context to maximize treatment efficacy. The discussion now turns to a review of these treatments, beginning with several existing case studies, and continuing on to an ongoing large case series study of 80 individuals with aphasia that focuses on treating the underlying verbal STM mechanism to maximize generalization to language production and comprehension.

EXISTING VERBAL SHORT-TERM MEMORY TREATMENTS FOR APHASIA

Though only a handful of verbal STM treatment studies have been conducted with individuals with aphasia, most of them performed within the past 15 years, the use of verbal STM tasks to treat linguistic impairments commonly associated with aphasia is not a new idea. In a 1987 case study by Peach,³⁷ an individual with aphasia due to a left hemisphere stroke demonstrated impaired sentence repetition, a hallmark symptom of conduction aphasia, among other predominately production-based linguistic impairments (e.g., confrontation naming, performance of commands). The goal of the study was to determine whether treating the individual with classic verbal STM tasks (i.e., immediate serial recall) would improve sentence repetition, a symptom of aphasia classically seen as linguistic in nature. Peach theorized that sentence repetition is subserved by a temporary linguistic storage mechanism, and thus, improvements on immediate serial recall of words should generalize to sentence repetition. The treatment included a pointing word span task, in which the participant heard two words and pointed to pictures corresponding to the two words in an array of 10 items, and a more traditional repetition word span task, during which the participant repeated three-word strings (consisting of a noun, verb, and functor, with order of presentation of each word class varied among the trials). The participant demonstrated a marked improvement in sentence repetition following treatment, which Peach argued resulted from a more general improvement in temporary maintenance of linguistic information (i.e., verbal STM).

The caveats of the study include the similarities of the verbal STM treatment tasks to the sentence repetition task targeted during treatment. Sentence repetition, though not frequently connected to verbal STM in the literature at the time of the study, directly involves the recall

of linguistic information. The improvement of sentence repetition following verbal STM treatment, then, is not surprising. It would be more interesting to see if the verbal STM treatment generalized to tasks not directly demanding the repetition of verbal information, such as picture naming and word reading. Although these abilities did improve in the participant following treatment, the addition of another treatment phase not exclusively targeting verbal STM (i.e., treatment involving following auditory commands) makes it difficult to attribute the improvement to the verbal STM portion of the treatment. Additionally, because the individual with aphasia participated in this treatment program less than 1-month poststroke, spontaneous recovery likely contributed considerably to improvements on classic language tasks. These issues aside, this case study was one of the first to incorporate verbal STM tasks into a treatment paradigm for aphasia, a decision motivated by the theory that verbal STM is a cognitive requirement of language processing.

More recent verbal STM case studies extend this work by investigating whether targeting verbal STM in chronic aphasia will generalize to classic language production and comprehension tasks. The studies reviewed later all rely on repetition paradigms in which verbal information must be briefly held active. They differ in several aspects, including the type of verbal information to be held in verbal STM (e.g., sentences, digits), the psycholinguistic properties of the verbal information (e.g., high- versus low-imageability words), the interval after which repetition of the verbal information occurs, and the level of feedback the patient receives after their response. The common thread among these studies is that they attempt to isolate the verbal STM component of language processing from attentional functions as much as possible, meaning that the focus of treatment is on the temporary storage rather than the active manipulation of verbal information. Notably, several working memory treatment studies designed for individuals with aphasia incorporate both temporary storage and manipulation of verbal information,^{38,39} but they are beyond the scope of this article. Additionally, studies that combine verbal STM treatment with more classic linguistic treatment tasks (e.g., spoken to written sentence matching) are not discussed.⁴⁰ Treatment studies that attempt to minimize both attentional load and the use of classic language tasks, and therefore to isolate the verbal STM component, inform the specific influence of verbal STM on language processing and elucidate the potential of verbal STM treatments to improve language production and comprehension. Because the influence of STM treatment on sentence comprehension is covered in another article in this issue, existing treatments that report on outcomes of language tasks with a production component (naming, discourse, and repetition) are reported here, whereas the several existing treatments specifically targeting sentence comprehension are not discussed.^{41,42}

One of the first case studies to target the more passive verbal STM system rather than the more active verbal working memory process utilized a word and nonword pair repetition treatment paradigm to treat an individual with aphasia characterized by phonological processing impairment.⁴³ The participant who received the treatment was a 50-year-old man with a left cerebrovascular accident affecting the posterior part of the superior temporal gyrus and parietal cortex. Although standardized tests revealed within normal limits word naming and sentence comprehension ability, the participant also demonstrated poor nonword repetition and a reduced digit span (approximately three items). The participant was deemed to have a severe deficit in maintaining phonological information. Treatment consisted of two

phases and entailed the repetition of word and nonword pairs. Phase I entailed immediate repetition of word and nonword pairs differing by one consonant, whereas phase II entailed delayed repetition of the same stimuli after a 5-second filled delay between target and recall, during which the participant had to count backward. After completion of both phases, the training program was repeated with word and nonword pairs differing by a single vowel. The study did not report the use of feedback, but participants had to repeat a pair correctly on two consecutive trials to advance to the next stimulus pair. Treatment continued for 16 months (eight sessions per month). The posttreatment assessment demonstrated modest improvements in digit and nonword repetition span length, and significantly more words correctly repeated in word repetition span. Interestingly, performance on the treatment task itself (i.e., minimal pair repetition) did not significantly change.

Because the participant described previously demonstrated strong picture naming abilities prior to the start of treatment, the potential of a minimal pair repetition treatment to improve word retrieval is unclear. Several recent case studies with anomic participants, though, demonstrated that verbal STM-based treatments have the potential to improve language production. Koenig-Bruhin and Studer-Eichenberger treated a 47-year-old, right-handed male who suffered an embolic infarction of the inferior branch of the left middle cerebral artery.⁴⁴ His aphasia was characterized by anomia and morphosyntactic errors in spontaneous speech. Additionally, he demonstrated impaired repetition of longer nouns and sentences. The authors classified his language impairment as conduction aphasia. Like the aforementioned word pair repetition paradigm, this treatment progressed from repetition of simpler to more complex targets and the introduction of a delay once immediate repetition was successful. The stimuli included sentences of four to seven words, and treatment progressed from shorter to longer sentences, and from no repetition delay to longer repetition delays ranging from 5 to 12 seconds. Feedback was given in two ways: the therapist repeated the incorrect targets to allow for additional attempts, and the sentence was presented orthographically to facilitate the response. Unique sets of stimuli were used in each session. Treatment continued for 17 weeks (two sessions per week). In addition to an improvement in sentence repetition and a modest improvement in digit repetition span length (from 3.4 to 4 items), the participants demonstrated increased sentence length in oral production, as tested by a picture description task, after treatment completion.

Similar to the sentence repetition treatment described previously, a more recent verbal STM treatment study utilized an immediate and delayed repetition paradigm with explicit feedback. Kalinyak-Fliszar and colleagues treated a 55-year-old, right-handed woman who suffered a left temporal intraparenchymal hemorrhage.⁴⁵ She was 29 months postonset at time of study enrollment, and demonstrated impaired word repetition span (~two items), naming, and lexical decision prior to treatment onset. Additionally, she demonstrated severe impairments on several repetition span measures, including nonword repetition and repetition of low frequency and low imageability words. She was described as mildly to moderately impaired in lexical-semantic processing and moderately to severely impaired in phonological processing. Treatment consisted of immediate and delayed repetition of high and low imageability words as well as nonwords that, like the two aforementioned treatments, progressed to a longer delay. Specifically, repetition progressed from a 1-second unfilled interval between the target and response, to a 5-second unfilled interval, to a 5-

second filled interval (the participant counted backward during the delay). In the case of incorrect responses, a hierarchical cueing paradigm ranging from the speech therapist's reproduction and correction of the participant's error to the multimodal training (visual and auditory) of each syllable in the repetition target was implemented. Treatment was administered three times per week for 45 to 60 minutes for 45 weeks. Posttreatment assessments demonstrated modest improvements on the repetition of both trained and untrained targets, as well as on the repetition of words, nonwords, word pairs, and sentences. Most importantly, the participant's picture naming improved (as measured by a time-constrained picture naming task requiring a rapid response). This treatment paradigm was later replicated with a second participant, who demonstrated similar improvements in repetition of trained and untrained stimuli and generalization to repetition span tasks, though naming performance was not reported.⁴⁶

The several aforementioned case studies demonstrate the potential of verbal STM-based interventions to improve performance on classic language tasks. However, these treatments vary considerably in terms of participant characteristics, treatment dosage, type of verbal information trained (e.g., nonwords versus sentences; high imageability versus low imageability words), verbal information load (e.g., words versus word pairs), and the delay imposed between stimulus presentation and recall. Larger studies are needed to elucidate the impact of each of these components on treatment outcomes. Martin and her colleagues at the Eleanor M. Saffran Center for Cognitive Neuroscience at Temple University are currently conducting a case series verbal STM treatment trial with 80 participants with aphasia and verbal STM impairments that has the potential to advance our understanding of the role of some of these verbal STM treatment components. The treatment lasts for 12 1-hour sessions, involves the repetition of real words, and varies the psycholinguistic properties of the trained information (concrete versus abstract words), verbal information load (words, word pairs, or word triplets), and delay imposed between the presentation and repetition of the word(s) (1 second, 5 seconds, or 10 seconds). Each participant receives one combination of these components during treatment (e.g., abstract word pairs at 5-second interval) based on their performance on a pretest that assesses the repetition of every possible component combination. For example, if the participant shows a fairly strong repetition of abstract word pairs at 1 second and 5 seconds and a sharp but not complete accuracy drop-off at 10 seconds, abstract word pairs with a 10-second interval may be a fruitful condition to treat, as the participant has a lot of room for improvement but demonstrates some latent ability at this condition. The goals of placing participants in a given treatment condition, then, is to assure that they are sufficiently challenged during treatment and have room to improve, while also making sure that the condition is not so difficult that individuals have little chance of improving their verbal STM processing capacity.

Along with tailoring the verbal STM treatment stimuli to each participant's pretreatment verbal STM capacity, a hallmark of this study is the use of unique stimuli, meaning that words are almost never repeated within or between the 12 treatment sessions. Each treatment session consists of two cycles of 20 unique items separated with a 10-minute break. The participants' only task is to listen to the word(s) produced by the experimenter, wait until the beep (occurring at 1, 5, or 10 seconds after stimulus presentation, depending on the treatment condition), and repeat what they heard in serial order. No experimenter feedback is

given during any of the treatment sessions. The use of unique items and the absence of feedback bring the focus to the more automatic verbal STM process itself rather than the repetition of specific words or the use of more explicit strategies to aid verbal STM recall. Because verbal STM is an integral underlying component of language processing, isolating the verbal STM process during treatment may optimize the potential of treatment to generalize to a variety of language production and comprehension tasks, thus enhancing its clinical utility. Though the study is in its beginning phases, the inclusion of a variety of language production and comprehension outcome measures will help determine the potential of this novel approach once more participants are treated and results are reported.

VERBAL SHORT-TERM MEMORY TREATMENT: WHAT WE KNOW AND WHERE TO GO NEXT

Though the study of verbal STM-based aphasia treatment is in its infancy, the several existing case studies illustrate some potentially fruitful approaches. They demonstrate that treating a specific verbal STM task (e.g., word pair repetition) generalizes to other verbal STM tasks (e.g., nonword span), suggesting that verbal STM interventions are process driven, leading to improvements in overall verbal STM processing rather than just improvements in treated tasks. Interestingly, several case studies have reported generalization of treatment to other verbal STM tasks either in the absence of an improvement on the trained verbal STM task or in the presence of only a modest improvement on the trained task.^{43,45} These results demonstrate that individuals can improve their verbal STM capacity regardless of whether they show marked improvements on the treatment task, and highlight the importance of using measures of verbal STM other than the treatment task to determine whether the verbal STM process improved as a result of treatment. Additionally, the studies reporting absent or modest improvements on the treated verbal STM task are also those that reported improvements in word production,^{44,45} demonstrating that verbal STM treatment-induced word production improvements do not have to occur in the presence of improvements in treated verbal STM tasks.

The development of verbal STM treatments for individuals with aphasia is in very early stages. Nonetheless, extant studies investigating the assessment and treatment of verbal STM in individuals with aphasia can still guide present clinical approaches. Effective treatments cannot occur without thorough language assessment, including an examination of the processes that drive language (e.g., verbal STM) in addition to classic language tasks. The inclusion of phonologically and semantically based verbal STM tasks in addition to the already widespread use of digit and word immediate serial recall tasks may help determine an individual's aphasia type. Additionally, an individual's tendency to err on low imageability words or words occurring in specific positions during span tasks may help determine whether the individual is more semantically or phonologically impaired.^{47,48} These assessment strategies, though, are biased toward understanding an individual's language *comprehension* impairment (i.e., receptive lexical-semantic or phonological processing). The ubiquitous use of repetition tasks to assess verbal STM favors phonological activation over lexical-semantic activation, because phonological selection begins prior to lexical-semantic selection in repetition-based and comprehension-based tasks. Conversely,

lexical-semantic activation is required to initiate word production in tasks such as naming and picture description. Thus, the STM assessment and treatment tasks reported in existing research are inconsistent with the activation timing of verbal representations during word production, and might thus not be as helpful in assessing and improving language production as they are in assessing and improving language comprehension.

Though much more complex than typical phonologically initiated verbal STM tasks, researchers at the Saffran Center for Cognitive Neuroscience at Temple University are currently developing a semantically initiated verbal STM task. The task will utilize picture stimuli of words that the participant can consistently name correctly, and will involve the retrieval of multiple picture names. Though the design of this semantically initiated STM task is methodologically challenging due to the necessity to tailor the stimuli to the participant completing the task, this approach may be more helpful in understanding the relationship between an individual's verbal STM and language production impairment than traditional immediate serial recall tasks. Another challenge of understanding the link between verbal STM and language production lies in the timing of classic language production tasks. Picture naming tasks, for example, often allow for long or unlimited response times,^{34,49} and discourse production in picture description tasks is sometimes analyzed without regard for how long the participant spoke.^{50,51} Imposing time constraints on these tasks will challenge verbal STM capacity and bring the requirements of these tasks closer to the verbal STM requirements of word production in natural settings. For example, Martin has designed a picture naming task that limits picture exposure to 2 seconds and allows only 5 additional seconds for the participant to respond.⁴⁸ These manipulations force the active retrieval of semantic features and the rapid retrieval of linguistic representations. Imposing time constraints on typical tests of language production, then, may increase the sensitivity and specificity of assessment of aphasia, eventually leading to the implementation of more effective treatment programs.

CONCLUSION

Extant theoretical and clinical research has demonstrated intricate connections between verbal STM and language processing. Although the field is young, the evidence to date has demonstrated the need for a shift from thinking about STM and language as two separate entities to elucidating the contributions of verbal STM to language production and comprehension. The belief that impaired access to language representations rather than the loss of these representations characterizes aphasia, an idea supported by decades of aphasia research, has prevailed in the past 20 years. The next logical step, then, is to ask what processes facilitate access to language representations, a question that has led to investigations of verbal STM and other cognitive processes (e.g., attention, working memory, executive function) in relation to linguistic impairments. Successful assessments and treatments of aphasia must carefully consider the incorporation of tasks that tax these processes to maximize generalization of aphasia treatment to clinically applicable language processing tasks.

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Learning Outcomes

As a result of this activity, the reader will be able to (1) explain the implications of an interactive linguistic activation view of verbal short-term memory on the treatment and assessment of aphasia; (2) summarize existing verbal short-term memory treatments for aphasia and discuss ongoing research that builds on this extant work.

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