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A new modified listening span task to enhance validity of working memory assessment for people with and without aphasia

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Abstract

Deficits in working memory (WM) are an important subset of cognitive processing deficits associated with aphasia. However, there are serious limitations to research on WM in aphasia largely due to the lack of an established valid measure of WM impairment for this population. The aim of the current study was to address shortcomings of previous measures by developing and empirically evaluating a novel WM task with a sentence-picture matching processing component designed to circumvent confounds inherent in existing measures of WM in aphasia. The novel WM task was presented to persons with (n = 27) and without (n = 33) aphasia. Results demonstrated high concurrent validity of a novel WM task. Individuals with aphasia performed significantly worse on all conditions of the WM task compared to individuals without aphasia. Different patterns of performance across conditions were observed for the two groups. Additionally, WM capacity was significantly related to auditory comprehension abilities in individuals with mild aphasia but not those with moderate aphasia. Strengths of the novel WM task are that it allows for differential control for length versus complexity of verbal stimuli and indexing of the relative influence of each, minimizes metalinguistic requirements, enables control for complexity of processing components, allows participants to respond with simple gestures or verbally, and eliminates reading requirements. Results support the feasibility and validity of using a novel task to assess WM in individuals with and without aphasia.

Keywords

working memory; working memory assessment; aphasia; cognitive processing; complex span tasks

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1. Introduction

Working memory (WM) can be broadly defined as "a multi-component system responsible for active maintenance of information in the face of ongoing processing and/or distraction" (Conway et al., 2005, p. 770). Compared to short-term memory (STM) (defined as a capacity for temporary storage of presented information) the concept of WM places a stronger emphasis on the notion of active manipulation of information instead of passive maintenance. Over the past 40 years WM capacity has been found to be related to higher cognitive tasks, including learning abilities, verbal reasoning skills, math skills, and language comprehension (Baddeley, 2003; Conway & Engle, 1996; Conway et. al., 2005; Cowan, 1999; Engle, Tuholski, Laughlin, & Conway, 1999; Just & Carpenter, 1992). From this perspective, WM may be contrasted with STM in that performance on STM tasks has not been found to be as strongly related to other specific cognitive abilities (Conway & Engle, 1996; Daneman & Carpenter, 1980; Engle, Tuholski, et al., 1999; Turner & Engle, 1989). Given evidence of a relationship between WM and language comprehension in normal language processing and evidence of limited WM capacity in individuals with aphasia (for a review see Murray, 2004; Murray et al., 2001; Wright & Fergadiotis, 2012; Wright & Shisler, 2005), studies of WM play an important role in understanding the nature of aphasia.

Early investigations of WM in aphasia referred to a rather nebulous construct of WM, postulating a limited capacity for language processing in aphasia and its negative impact on linguistic performance. Tompkins, Bloise, Timko, and Baumgaertner (1994) were the first to demonstrate reduced WM capacity in individuals with left hemisphere damage, some of whom had aphasia. Later, Caspari, Parkinson, LaPointe, and Katz (1998) demonstrated a relationship between WM capacity and general measures of language impairment, such as the Western Aphasia Battery (Kertesz, 1982) and Reading Comprehension Battery for Aphasia (LaPointe & Horner, 1979). More recently, researchers have investigated specific aspects of memory impairments in aphasia and their differential relationships with various language abilities (Christensen & Wright, 2010; Friedmann & Gvion, 2003; Laures-Gore, Marshall, & Verner, 2011; Martin & Reilly, 2012; Mayer & Murray, 2012; Sung et al., 2009; Wright, Downey, Gravier, Love, & Shapiro, 2007). A more in-depth understanding of the role that WM plays in language processing in aphasia is important for conceptualizing the nature of aphasia, developing valid and reliable assessment methods, and providing optimal treatment while taking cognitive factors into account. However, despite almost two decades of research on the nature of WM in aphasia, understanding of the construct and its specific relationship to language abilities in aphasia remains limited. Key limitations of the existing research are that: (a) WM tasks have been modified in different ways, making the comparison or aggregation of data across studies problematic (Connor, MacKay, & White, 2000; Ivanova & Hallowell, 2012; Murray et al., 2001; Wright & Fergadiotis; Wright & Shisler); (b) WM tasks used with people who have aphasia are often not designed to take into account potentially confounding factors associated with task requirements and measurement validity (Ivanova & Hallowell, 2012; see Wright & Fergadiotis, 2012 for a related argument); and (c) stimulus design and procedures are often not described in sufficient detail, making it difficult to understand specific task requirements, interpret results, and compare findings with those of other studies. In addition to these methodological limitations, previous studies on WM and aphasia have included heterogeneous aphasia groups and the observed effects were interpreted as if they applied to the whole sample. Aside from work by Friedmann and Gvion (2003) no previous study has entailed analysis of the relationships between WM and severity of language deficits within aphasia subgroups. The present study was designed to address these limitations. In this introduction we will briefly review the nature of tasks used to study WM in aphasia and specific associated task design limitations. We will then provide a rationale for a new WM task and describe a study aimed at validating the use of that task with people with and without aphasia.

1.1 Measuring working memory in aphasia

Several different tasks have been used to index WM in aphasia. They may be generally categorized as complex span, N-back, and backward span tasks. Complex span tasks are the focus of the current investigation because: (a) they are among the most widely used measures of WM in behavioral studies of children and adults without neurological, cognitive or language impairments; (b) their construct validity has been substantially supported in the literature (for a review see Conway et al., 2005; Waters & Caplan, 2003); (c) they have been shown to have high internal consistency and test-retest reliability (Kane et al., 2004; Waters & Caplan, 2003); (d) WM span task performance has been consistently related to performance on a broad array of higher-order cognitive tasks, such as verbal reasoning, listening and reading comprehension, math skills, and learning ability (e.g., Conway & Engle, 1996; Engle, Kane, & Tuholski, 1999; Just & Carpenter, 1992; Turner & Engle, 1989); and (e) authors of various theoretical models of WM regard performance on complex span tasks as valid indices of WM (Baddeley, 2003; Cowan, 1999; Engle, Kane, et al., 1999; Just & Carpenter; Towse, Hitch, & Hutton, 2000) (even though different explanations have been offered as to why a span score represents WM capacity).

Although N-back tasks have also been used (e.g., Friedmann & Gvion, 2003; Wright et al., 2007; Christensen & Wright, 2010; Mayer & Murray, 2012), their use to measure WM capacity has inherent validity problems. Results of numerous studies indicate no significant correlations with performance on complex span tasks in adults without cognitive or language impairments (e.g., Jaeggi, Buschkuehl, Perrig, & Meier, 2010; Jaeggi, Studer-Luethi et al., 2010; Kane, Conway, Miura, & Colflesh, 2007; Oberauer, 2005; Roberts & Gibson, 2002). Moreover, performance on N-back tasks has been more strongly related to performance on simple span tasks indexing short-term memory (Jaeggi, Buschkuehl et al.; Oberauer; Roberts & Gibson; see Jaeggi, Buschkuehl et al. for a detailed discussion on concurrent and construct validity of N-back tasks). Additionally, none of the well-established theories of WM endorse the N-back as a valid measure of WM (see Chien, Moore, & Conway, 2011 for an extended argument). Similar validity issues have been encountered with backward span tasks. For example, Waters and Caplan (2003) reported that adults without neurological impairments showed that performance on backward span task loads on the same factor as complex span tasks, although Engle, Tuholski, Laughlin, and Conway (1999) countered that finding.

1.2 The nature of complex-span tasks to date

Caspari et al. (1998) and Tompkins et al. (1994) used different versions of the original Daneman and Carpenter (1980) reading/listening span tasks with syntactically simpler and shorter sentences. In a typical complex span task (or WM span task), a processing task (e.g., sentence reading, arithmetic problem-solving, visual-spatial tracking), is given along with a set of stimuli (e.g., letters, words, shapes) to be remembered for later recall. This task was originally based on a simple span task and designed to tap specifically into WM. Starting with those initial investigations, sentences have been modified to ensure that the processing component is simple enough for participants with language impairment to achieve desired levels of accuracy (Murray & Chapey, 2001; Murray & Clark, 2006). Caspari and colleagues (1998) proposed another important alteration of the task by substituting recall of to-be-remembered items with recognition of pictorial representations of words; this minimized reliance on reading and expressive language abilities, which otherwise might have confounded results.

1.3 Addressing problems with existing complex span tasks for people with aphasia

Although complex span tasks are promising as measures of WM for individuals with aphasia, the tasks used in studies to date remain problematic. Problems addressed here include controlling for length versus complexity, attending to metalinguistic demands, controlling for complexity of processing components, allowing alternative modes of response, and taking into account the demands of recall versus recognition tasks.

1.3.1 Controlling for length versus complexity—The content of the processing component of WM is one of the important facets of span tasks. Both length and complexity have been altered simultaneously in complex sentence span tasks used to tap WM in aphasia. Potential effects of short but complex sentences or, alternatively, long but syntactically simple sentences have not been explored. Martin (1995) advocates for differentiation of semantic and syntactic subcomponents of WM, in addition to the phonological component described by Baddeley (2003). Martin and Romani (1994) demonstrated that semantic and syntactic complexity of sentences has a differential effect on comprehension of individuals with aphasia, depending on which component of the WM system is affected. Caplan, Waters, and Hildebrandt (1997) showed that syntactic complexity (canonicity of thematic role in the sentence) and number of propositions each had a separate impact on comprehension of sentences by individuals with aphasia. Later, Caplan and Waters (1999) emphasized that comprehension in persons with aphasia is especially vulnerable to increases in syntactic complexity because WM required for on-line sentence processing (the separate sentence interpretation resource) is impaired in individuals with aphasia. At the same time, researchers investigating short-term memory in aphasia demonstrated that length of utterance, which directly impacts the number of items that must be activated to comprehend a sentence, is a critical factor underlying comprehension (Martin & Ayala, 2004; Martin & Saffran, 1997, 1999). It is possible that each of these factors – length and complexity – may have differential influences on performance of persons with and without aphasia on WM span tasks and may impact WM capacity of some individuals but not others (Murray & Chapey, 2001). Moreover, investigating differentially the impact of length versus complexity could help to tease apart critical factors in competing theoretical models, that either predict that WM would be particularly susceptible to time-based interference and duration of retention interval (Engle, Kane, et al., 1999; Cowan, 1995; Towse et al., 2000) versus difficulty of the processing component per se (Just & Carpenter, 1992), or perhaps neither (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Unsworth & Engle, 2008).

1.3.2 Attending to metalinguistic demands—Another important concern regarding the processing component of reading/listening span tasks is that it often entails true/false judgments (e.g., Friedmann & Gvion, 2003; Sung et al., 2009; Tompkins et al., 1994; Wright et al., 2003). The metalinguistic skills required may pose additional problems for participants with language impairments. Comprehension questions entail fewer metalinguistic demands and may be considered to be more natural in terms of typical language use. However, presentation of a comprehension question following each sentence might involve excessive interference and impede performance of people with aphasia on the storage component of the task. To avoid this complication, Caspari et al. (1998) provided one or two randomly selected comprehension questions at the end of a set of sentences of the same length, to ensure that participants were attending to the content of the sentences. However, this is a problematic approach to measuring comprehension/processing because the processing task also involves storage, thus confounding the processing measure, and the obtained data are insufficient for analysis of performance on the processing component.

1.3.3 Controlling for complexity of processing components—The impact of the complexity of the linguistic processing component on WM capacity of individuals with aphasia has not been thoroughly investigated, and the validity of comparisons between people with and without aphasia on modified complex span tasks is not clear. When the processing component is simplified, it is unknown how difficult such tasks are overall for adults without any cognitive nonlinguistic or language impairments and whether they reflect true WM capacity or simply short-term storage (Turner & Engle, 1989). A related dilemma is that individuals with mild receptive language deficits are likely to have a contingent advantage on such tasks compared to those with more pronounced comprehension impairments, which would improve their WM scores regardless of their true WM capacity. There are no published studies clearly demonstrating what kind of sentences should be presented in the processing component of complex span tasks to participants with aphasia.

1.3.4 Allowing alternative modes of response and implementing a recognition versus recall task—People with aphasia are often limited in their ability to respond verbally and/or gesturally due to concomitant motor speech and limb-motor deficits, all of which may confound performance in complex span tasks used to date. It is important to evaluate carefully various stages of WM tasks and their corresponding requirements, and to challenge direct comparisons of people with and without aphasia on tasks in which such concomitant deficits might be implicated. Allowing a pointing or gestural response alternative to spoken responses is important, although rarely done because of the reliance on verbal recall in most complex span tasks.

Caspari et al. (1998) adapted the memory component of complex span tasks, replacing the traditional recall task with recognition of pictorial representations of words. They found a high correlation (.57) between performance of 24 undergraduate student participants without neurological impairments on a reading span task with a recognition component and reading comprehension (verbal SAT) scores. The authors interpreted this result as evidence that changing the typical recall task to a recognition task did not alter the construct validity of the WM task. However, concurrent validity of the modified task would be ideally indexed through the correlation of performance on complex span tasks with recall and recognition, which has not been reported to date. Also, participants in the Caspari et al. study were presented with long complex sentences, as in the original Daneman and Carpenter (1980) task; use of recall task with short and simple sentences has not been reported.

1.3.5 Methodological validation—Overall, there are many unresolved concerns regarding what WM tasks and measures are most valid and reliable for use with individuals with aphasia. It cannot be assumed that the established high reliability and validity of traditional complex span tasks (Conway et al., 2005) hold for adapted versions involving modification of content and structure. Limited attempts have been made to validate modified versions of WM span tasks. In sum, there is great need for research to establish methodologically, theoretically, and psychometrically sound measures appropriate for use with people with aphasia. Development of such measures will enable more thorough and valid investigation of the role of WM in aphasia.

1.4 Aims of the current study

The primary goal of this study was to develop and test the concurrent validity of a WM complex span task suited for individuals with aphasia and establish the psychometric properties of associated performance measures. The modified listening span (MLS) task developed is a simplified version of the Daneman and Carpenter (1980) listening span task. The following task design features were implemented to address each of the limitations of existing tasks described above:

1. Differential control for length and complexity of verbal stimuli;
2. Minimal metalinguistic demands;
3. Control for complexity of processing components;
4. Allowance for a pointing response as an alternative to spoken responses, eliminating reading requirements, and implementing a recognition task instead of a typical recall task.

Specific aims and hypotheses of the study were to:

1. Test the concurrent validity the MLS task by studying the relationship between performance on the MLS task and performance on a traditional listening span (TLS) task (Kane et al., 2004) in people without aphasia. We anticipated that performance on the two tasks would be significantly correlated.
2. Investigate the impact of separately manipulating length and syntactic complexity of sentence stimuli in the linguistic processing component of the MLS task on WM capacity indexed for adults with and without aphasia. We hypothesized that performance of individuals without aphasia would not be affected by manipulation

of length and complexity of the processing component. No directional hypothesis was posed for the aphasia group, given that this aspect of complex span tasks has not been previously investigated in participants with aphasia.

3. Contrast performance of participants with and without aphasia on the MLS task. We expected participants with aphasia to perform significantly more poorly on the WM task across all conditions.

4. Examine the relationship between WM capacity as indexed by the MLS task and standardized language measures (especially auditory comprehension) in participants with aphasia. We hypothesized that there would be a significant relationship between standardized measures of auditory comprehension and WM capacity as indexed by the MLS task. Additionally, we tested whether this relationship differed across groups of individuals with varying levels of language impairment severity.

2. Methods

2.1 Participants

The study was approved by the Institutional Review Board of Ohio University. Inclusion criteria for participants with and without aphasia were: (a) chronological age within range from 21 to 80 years; (b) status as a native speaker of American English; (c) intact visual acuity for near vision as assessed with the Lea Symbols Line test (Precision Vision) containing symbols that vary in size (Hyvärinen, Näsänen, & Laurinen, 1980); and (d) hearing acuity screened at 500, 1000, and 2000 Hz at 40 dB SPL. Additionally, intactness of visual fields was evaluated with an Amsler grid and a confrontation finger counting test, and extraocular motor functions and pupil reflexes were screened and documented (Hallowell, 2008).

2.1.1 Participants without language impairment—Additional inclusion criteria for individuals without aphasia were: (a) no reported history of speech, language, or cognitive impairment; (b) no reported history of neurological impairment; and (c) performance within the normal range on the Mini-Mental Status Examination (Folstein, Folstein, & McHugh, 1975). Thirty-three participants without aphasia, 23 females and 10 males, age 22 to 80 years (M = 55.3, SD = 16.8), participated. Years of post-high-school education ranged from 2 to 14 years (M = 5.8, SD = 3.1).

2.1.2 Participants with aphasia—Additional inclusion criteria for individuals with aphasia were: (a) diagnosis of aphasia due to stroke as indicated in a referral from a neurologist or a speech-language pathologist and confirmation via neuroimaging data; (b) no reported history of speech, language, or cognitive impairment prior to aphasia onset; and (c) post-onset time of at least two months to ensure reliability of testing results through traditional and experimental means. Aphasia in this study was defined as "an acquired communication disorder caused by brain damage, characterized by an impairment of language modalities: speaking, listening, reading, and writing; it is not the result of a sensory deficit, a general intellectual deficit, or a psychiatric disorder" (Hallowell & Chapey, 2008, p. 3). Only individuals who had aphasia due to stroke were recruited. Participants with a variety of aphasia subtypes and sites of lesion were sought. Type of aphasia was otherwise not considered an important element of experimental design in this context as it has not been shown to be useful in the identification of linguistic deficits associated with aphasia (Caramazza, 1984; McNeil & Kimelman, 2001; McNeil & Pratt, 2001; Wertz, 1983). Furthermore, there is a lack of evidence that WM deficits manifest consistently within aphasia subtypes (McNeil et al., 2004). Additionally, previous studies investigating WM in aphasia also incorporated groups with mixed aphasia subtypes and varying severity of language deficits. Most importantly, in accordance with the aims of the study, it was important to test the validity of the MLS task as a tool to index WM in individuals with a broad range of language deficits and to explore how severity of aphasia relates to different patterns of performance on the WM task.

Twenty-seven right-handed participants with aphasia, 10 females and 17 males, age 22 to 78 years (M = 56.2, SD = 12.3), participated. Years of post-high-school education ranged from 0 to 9 years (M = 4.8, SD = 2.8). Months post-onset ranged from 10 to 275 months (M = 64.9, SD = 57.5). Detailed participant characteristics are given in Appendix 1.

There were no significant differences in age or years of education between participants with and without aphasia (age: t (57.3) = −0.242, p = .809; education: t (58) = 1.329, p = .189). Per vision screening results, six participants with aphasia had visual field deficits. All were able compensate using head movement and pointed accurately to images in all four quadrants such that these deficits did not appear to influence performance on the experimental tasks. No participants showed symptoms of visual neglect upon screening.

Participants with aphasia were administered the Aphasia Quotient (AQ) components of the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2007). WAB-R spontaneous speech scores ranged from 8 to 20 (M = 14.67, SD = 3.4); auditory verbal comprehension from 5.4 to 10 (M = 8.75, SD = 1.25); repetition from 1.7 to 10 (M = 7.8, SD = 2.04); and naming and word finding from 3.7 to 10 (M = 7.77, SD = 1.76). AQ scores ranged from 45.1 to 99.4 (M = 77.97, SD = 15.21). Classifications according to the WAB-R indicated that 15 individuals had mild aphasia (according to WAB-R guidelines individuals with AQ from 76 to 100 are classified as mild), 10 moderate (AQ from 51 to 75), and 2 severe (AQ from 26 to 50). Further according to the WAB-R classification 4 individuals had Broca’s, 3 Transcortical motor, 18 Anomic, and 2 both Anomic and Conduction aphasia.

2.2 WM tasks

2.2.1 Traditional listening span (TLS) task—This task was completed only by participants without aphasia. This was a listening span task in its most commonly used form. Participants without aphasia listened to sentences, verified their semantic plausibility, remembered a set of separately presented words, and then recalled the individual words at the end of each sentence set. The sentence stimuli consisted of 40 compound sentences, 12 to 15 words in length; half of the sentences were nonsensical. The sentences were Kane et al.’s (2004) reading span task. Words to be remembered were one-syllable, high-frequency (from 18/million to 2110/million [Francis & Kucera, 1982]), concrete, phonologically simple words that were not associated with the meaning of the sentences. All linguistic stimuli were presented auditorily via computer speakers at 70 dB. After making the judgment of whether the sentence was meaningful or not participants immediately heard a word for subsequent recall and proceeded to the next sentence. At the end of the set they were to recall the separately presented words in serial order. Sentence-word pairs were presented in sets of 2 to 6 in ascending order; two sets of each size were presented.

The following measures were used to index performance on the TLS task:

1. Storage scores were based on a partial credit unit scoring scheme (Conway et al., 2005). Items were scored as proportion of correctly sequentially recalled elements per set; for the final score a mean of these proportions was calculated. Items recalled out of order were scored as incorrect responses. The storage score was regarded as an index of WM capacity.

2. Processing scores were expressed as the proportion of correctly judged sentences.

2.2.2 Modified listening span task—This task was completed by participants with and without aphasia. Participants were asked to listen to sentences and remember a separate set of words for subsequent recognition. Length and complexity of sentences were manipulated separately, creating conditions with: (a) short and simple; (b) short and complex; (c) long and simple; and (d) long and complex sentences. The MLS task was presented in each of the four conditions to enable investigation of the differential impact of length and syntactic complexity.

Short sentences were 7 to 9 syllables in length (6 to 7 words) and long sentences were 15 to 18 syllables (13 to 17 words). Active sentences were used in the simple conditions, and passive sentences in the complex conditions. Passive sentences are more syntactically complex compared to active sentences because they require processing of a noncanonical order of thematic roles. Individuals with aphasia have been shown to have difficulty comprehending and producing passive compared to active sentences (Berndt, Mitchum, Burton, & Haendiges, 2004; Berndt, Mitchum, & Haendiges, 1996; Caplan & Waters, 1999; Caplan et al., 1997). An additional advantage of using passive sentences for the complex condition is that they allow manipulation of syntactic complexity without significantly impacting sentence length.

All sentences were semantically and syntactically plausible, and semantically reversible. High-frequency words (from 5/million to 2110/million [Francis & Kucera, 1982]) were used. For the agent and patient, the words woman, man, boy, and girl were used; length of sentences was increased through the use of descriptor words (adjectives, adverbs, and prepositional phrases). Verbal stimuli were prerecorded and digitized. Examples of sentences from the four conditions are presented in Table 1.

The processing component was measured in a novel way not previously attempted in aphasia or non-impaired control group research. Together with each sentence, multiple-choice visual arrays were presented, each consisting of four pictures, one picture in each of the four corners of the display. The verbal stimulus (sentence) corresponded to one of the images (the target) in the multiple-choice arrays while the other three images served as foils. Pictures used in the multiple-choice arrays were grayscale images created by a professional artist with extensive experience in developing visual stimuli specifically designed to minimize the influence of visual image characteristics on allocation of attention (Heuer & Hallowell, 2007, 2009). In the MLS task participants were asked to select the image that best matched the sentence. This task relies less on metalinguistic abilities than true/false judgments do and provides a more accurate index of performance on the processing component of the WM task compared to random comprehension questions.

The three foil pictures differed from the target by subject, object, and/or action. For example, for an array with the verbal stimulus *The woman is kissing the man*, the target image was a woman kissing a man and the foils were a man kissing a woman (grammatical foil with reversed agent-patient roles), a woman finding a man (different action), and a man finding a woman (different action with reversed agent-patient roles). Foils created this way allowed any picture to be the target while maintaining the specific semantic relations between the target and foils. The location of the target in each quadrant was counterbalanced across trials.

In the piloting phase of the experiment the semantic content of the pictures was evaluated to ensure that the images used in the WM tasks unambiguously depicted what they were intended to represent. Participants (20 native speakers of English without a history of language, cognitive nonlinguistic, or neurological impairment [age range: 21 to 59 years, *M* = 29.65, *SD* = 9.17; 14 females and 6 males]) were asked to describe what they saw in each picture. All images for which 100% of verbal picture descriptions accurately indicated the intended content of the images were retained for the main experiment. For those cases in which any participant's description did not match the intended content, both authors along with an additional investigator with extensive experience in stimulus design for aphasia research, discussed the given verbal response and suggested revisions to the image so that it would clearly convey the intended content. The graphic artist then implemented the suggested changes until there was 100% agreement amongst the three judges regarding the effectiveness of the image to convey the targeted content.

Items to be remembered were separate words presented after each sentence, rather than sentence-final words. Using words unrelated to the sentences provided more control over word frequency and picturability of to-be-remembered items; also, it made the MLS task more closely resemble the TLS task. The frequency of words to be remembered ranged from 13/million to 717/million (Francis & Kucera, 1982). The recall component was changed to rely solely on recognition (as was done previously by Caspari et al., 1998) rather than on overt verbal expression required for recall. This ensured that possible concomitant expressive language and motor speech deficits did not confound performance. At the end of each sentence set, an array of target images (representing words presented following each sentence in that set) and foil images (equal to the number of target images) were presented for recognition. Foil images represented constructs from the same semantic category as the target images. Participants were asked to point to the target images or just name the words. To minimize possible interference between to-be-remembered words and equalize difficulty of to-be-remembered items across sets, all to-be-remembered words within a set were from different semantic categories and did not rhyme with each other. The pictures for the recognition displays were taken from a large online image databank courtesy of Michael J.

Tarr, Brown University, http://www.tarrlab.org. These images were developed by Rossion and Pourtois (2004), and are adapted versions of the 260 line drawings initially created by Snodgrass and Vanderwart (1980). The images are normed for naming agreement, familiarity, complexity, and imagery judgments. In the current experiment grey-shaded versions of these images were used. An example of a set from the MLS task is presented in Figure 1.

The MLS task was presented on a 14-inch computer screen. Verbal and visual stimuli for the processing component were presented simultaneously. Participants were asked to point to the corresponding images for the processing and storage components of the task. Given that motor control is a well-known confounding factor for people with neurological disorders, response times were not recorded; performance was evaluated only in terms of accuracy.

Participants were given the following instructions: "You will hear spoken sentences and see pictures. First point to the picture that goes with the sentence as quickly as you can. Then listen to the word. Remember it. After several words point to the pictures that go with the words." Once they pointed to an image in the multiple-choice array, an item to be stored was presented auditorily, followed in 1.5 seconds by the next processing item or a recall cue. Prior to the experimental task practice trials were given to insure comprehension of instructions.

In the MLS task, sets of 2 to 6 sentences were presented in ascending order. One set of each set size was presented within each condition. The same 20 multiple-choice arrays were presented in each of the four conditions. A verbal stimulus corresponding to a different image accompanied the multiple-choice array in each condition, requiring participants to identify a new target. For each set size, the four conditions of the MLS task were presented in the following order: short and simple; short and complex; long and simple; and long and complex.

The following measures were used to index performance on the MLS task:

1. Storage scores were computed similarly (based on a partial credit unit scoring scheme) to the storage score for the TLS task (only for recognized rather than recalled items; order of recognition was not taken into account).
2. Processing scores were expressed as the proportion of items for which the target picture was correctly selected.

These two scores were computed for each of the MLS task conditions. Also, overall storage and processing scores, expressed as a mean of each of the scores across the four conditions, were calculated.

3. Results

3.1 Descriptive statistics and preliminary analyses

Descriptive statistics (mean, standard deviation, minimum, and maximum) for the WM scores (storage and processing) on the TLS and the MLS tasks plus reliability coefficients (Cronbach's alpha) for each of the conditions on the MLS task for participants with and without aphasia are presented in Table 2. Individual overall storage and processing scores for the MLS task of participants with aphasia can be found in Appendix 1.

Prior to running the main statistical analyses, all WM scores were screened for normality using the Kolmogorov-Smirnov test with Lilliefors correction. All scores of participants with aphasia were normally distributed. For participants without aphasia only the processing scores of the MLS task were non-normally distributed (due to a strong ceiling effect and, as a result, a negatively skewed distribution). Various transformations were attempted to normalize the data but the strong ceiling effect precluded significantly improved normality. All the analyses were done using both parametric and nonparametric methods. The two approaches provided identical results in terms of identifying significant relationships and effects. Violation of the normality assumption was unlikely to have impacted results. Given the relatively large sample size, the interval/ratio level data, the primary focus on absolute values rather than rank of scores, and the fact that parametric tests are more powerful, the analyses using parametric statistics are reported here.

There was a significant negative correlation between performance on the storage component of the TLS and MLS and age for both groups of participants (controls: TLS task $r = -.465$, $p = .006$; MLS task $r = -.418$, $p = .016$; aphasia: MLS task $r = -.386$, $p = .047$).

3.2 Traditional listening span task

Pearson's correlations were analyzed among TLS scores and WM scores from the four conditions of the MLS task and the overall MLS task score. See Table 3 for results of all controls, excluding one participant eliminated from analysis because his performance on the processing component of the TLS task was more than 2 SDs below the mean (Tabachnick & Fidell, 2007).

Following the Holm adjustment (Holm, 1979) to control for familywise alpha at .05 only the correlations between storage scores on the two tasks were significant; there was no significant relationship between the processing scores.

3.3 Performance on different conditions of the modified listening span task

The impact of sentence stimuli on performance of participants with and without aphasia on the MLS task was explored. A repeated-measures ANOVA[1] was performed on the processing and storage scores for the four conditions of the MLS task (see Table 4) with two within-subject variables: length and complexity. Data from participants with and without aphasia were analyzed separately.

As can be seen from Table 4 only the length factor had a significant impact on WM storage scores of participants without aphasia: it negatively influenced recall (indexed by recognition) performance. Recall of individuals with aphasia was unaffected by length or complexity. At the same time, the interaction between length and complexity was significant

[1]The only violation of assumptions of ANOVA was the non-normal distribution of data for the processing component of the MLS of participants without aphasia. No significant effects were expected here and none were observed (i.e., conditions of the MLS task did not impact performance of participants without aphasia on the processing component of the task) - a finding not central to the main purpose or conclusions of the study.

for individuals with aphasia. As length of sentences increased, recall performance on simple sentences improved, and performance on complex sentences declined. When the recall data of the two participants with severe aphasia (determined according to the AQ of the WAB-R (Kertesz, 2007)) were removed from analysis the interaction between length and complexity was nonsignificant, while other significant effects remained unchanged. Thus, the interaction had been driven primarily by the results of those two individuals. Both length and complexity had a negative impact on processing performance of participants with aphasia.

3.4 Comparison of performance between participants with and without aphasia

Differences in WM scores between participants with and without aphasia were explored using univariate general linear model analysis, with age and years of higher education as covariates. Participants with aphasia obtained significantly lower WM scores than individuals without aphasia across all conditions of the MLS task (see Table 5).

Separate independent-samples t tests were implemented to compare performance of nine participants with mild comprehension deficits (WAB-R Auditory Comprehension scores ranging from 9.55 to 10) to participants without language impairment on the MLS task. Differences in overall storage (t (40) = 4.55, p < .001) and overall processing scores (t (40) = 4.26, p < .001) were significant.

3.5 Relationship between working memory capacity and language abilities

To investigate the relationship between WM capacity and general language abilities, WM scores were correlated with subtest scores and the AQ of the WAB-R (Kertesz, 2007) (see Table 6). After the Holm adjustment (Holm, 1979) to control for familywise alpha at .05 was applied only the correlations between MLS processing scores and WAB-R subtest scores at or above .6 remained significant; all correlations between MLS storage scores and subtest scores became non-significant.

The relationship between WM capacity and auditory language comprehension was further analyzed according to aphasia severity levels as identified by the WAB-R (Kertesz, 2007). This relationship is demonstrated graphically in Figure 2.

For the mildly impaired group (n = 15) a positive trend was observed between overall storage scores and auditory comprehension (AC) scores (r = .413, p = .126), with the relationship becoming significant when only storage scores from the short and simple condition were included in the analysis (r = .594, p = .019). At the same time the correlations between processing scores of the MLS task and AC subtest were non-significant (r = .383, p = .159). For the moderately impaired group (n = 10), none of the storage scores were related to AC subtest (overall storage score: r = −.060, p = .870; short and simple condition storage scores: r = .070, p = .848), while the processing scores were significantly related (r = .684, p = .029). No correlational analysis was performed in the severe aphasia group since it included only two participants. There was no significant difference between the mild versus the moderately impaired group in terms of overall storage scores (M = .76 and M = .72 respectively; t (23) = 0.92, p = .365) or storage scores from the short and simple

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condition (M = .75 and M = .70 respectively; t (23) = 0.88, p = .390). Additionally, when age was partialed out of the correlations between WM storage scores and AC scores the observed pattern of performance for both aphasia groups remained unchanged.

4. Discussion

4.1 Concurrent validity of the modified listening span task

The concurrent validity of a simplified complex span task as a measure of WM capacity was established. Significant correlations between a widely recognized measure of WM capacity (storage scores on the TLS task) and storage scores on the MLS task in adults without cognitive, linguistic, or neurological impairment demonstrate that the novel task provides a viable index of WM capacity. Correlations of the storage scores between the two WM tasks are similar in magnitude when compared to correlations reported among various WM tasks in the literature (Engle, Tuholski, et al., 1999; Kane et al., 2004). Notably, this relationship was observed even though the processing demands of the two WM tasks were demonstrably different and sequential recall was substituted for order-free recognition in the MLS task.

Having to switch between processing and storage appears to be effective for tapping into WM resources even when one of the processing tasks is fairly simple. This is consistent with attentional theories of WM, which equate WM capacity to a domain-general ability to allocate attention between two components of a given task, keeping relevant information activated despite possible ongoing interference (Cowan, 1999; Engle, Kane, et al., 1999; Engle, Tuholski, et al., 1999; Kane, Bleckley, Conway, & Engle, 2001; Kane et al., 2004; Turner & Engle, 1989) or rapidly switching attention between competing representations (Barrouillet et al., 2007; Unsworth & Engle, 2008).

4.2 Patterns of performance on the MLS task when controlling for length versus complexity

4.2.1 Individuals without aphasia—For participants without aphasia, there were no differences in processing scores among the four conditions. In other words, no significant impact of length or complexity of linguistic stimuli was detected on performance of the processing component of the MLS task. This was anticipated because all the sentences were well within the participants' comprehension abilities and ceiling effects were observed for all four conditions.

Significant differences in storage scores among the four conditions were observed due to the impact of length of linguistic stimuli in the processing component on recall. The long sentences not only prevented rehearsal, but also increased interference and storage duration, potentially inducing decay of words to be remembered. This explanation is consistent with attentional accounts of WM (cf., Engle, Kane, et al., 1999; Engle, Tuholski, et al., 1999; Turner & Engle, 1989), especially with Cowan's (1995, 1999) embedded processes model of WM, which states that short-term memory is temporally limited and items that are not rehearsed or processed within a certain time disappear. Towse, Hitch, and Hutton (1999, 2000) also proposed that the duration of the retention interval impacts recall.

The observed recall performance of individuals without aphasia cannot be directly compared to previously reported findings due to differences in linguistic stimuli and task requirements. Waters and Caplan (1996) detected an effect of complexity on recall in a complex span task. Cleft-subject and object-subject sentences in the processing component of the task led to higher recall scores compared with cleft object and subject-object sentences. Several studies have previously demonstrated that comprehension of cleft-object and subject-object sentences is more difficult relative to cleft-subject and object-subject sentences both in neurologically unimpaired controls (Dick, Bates, Wulfeck, & Dronkers, 1998; Miayke, Carpenter & Just, 1994) and in individuals with aphasia (Dick, Wulfeck, Bates, Naucler, & Dronkers, 1999; Hickok & Avrutin, 1995). Comprehension of cleft-object sentences is potentially more difficult than passive sentences. For instance, Miayke and colleagues (1994) showed that passives were comprehended more accurately than cleft-object sentences under strong temporal demands in normal adults. Similarly, Dick and colleagues (1998) reported that active and subject cleft sentences were comprehended faster and more accurately than passives and object clefts, with the later leading to slowest response times and poorest accuracy. A lack of cleft-object sentences in the stimuli used in the current study may be why the effect of complexity on performance was not detected. Overall few studies have specifically examined impact of the difficulty of the processing component of a span task on storage performance. Turner and Engle (1989) found that scores on reading and operation span tasks of moderate difficulty correlated more strongly with language comprehension measures compared to easy and difficult span tasks. However, they did not directly investigate differences in recall among the three conditions, and they manipulated length and syntactic complexity of sentences simultaneously. Both Waters and Caplan (1996) and Turner and Engle (1989) also required participants to make metalinguistic judgments about plausibility of the sentences in reading span tasks. On a side note, Conway and Engle (1996) did not find evidence of any influence of difficulty of arithmetic equations on recall in an operation span task of participants without cognitive or language impairment. These findings suggest the possibility that, until the processing component of a complex span task exceeds a certain level of difficulty, it will not have an impact on storage capacity.

4.2.2 Individuals with aphasia—Unlike control participants, participants with aphasia demonstrated differences in processing scores among the four conditions. Passive sentences were more difficult to understand compared to active (as indexed by lower processing scores), and longer sentences were more difficult than short ones. These results were anticipated, given that comprehension deficits are characteristic of aphasia, and that individuals with aphasia tend to have difficulties understanding sentences with noncanonical thematic role orders such as passives (Berndt et al., 1996, 2004; Caplan & Waters, 1999; Caplan et al., 1997; Dick et al., 1999; Hickok & Avrutin, 1995).

At the same time, there were no differences in storage scores among the four conditions of the MLS task. Neither complexity nor length of sentences by itself impacted recall, yet the interaction between length and complexity reached significance for participants with aphasia. As length of sentences increased, recall performance on simple sentences improved, and performance on complex sentences declined. This finding should be interpreted cautiously because when the data of the two participants with severe aphasia were removed the interaction between length and complexity became nonsignificant.

There are three plausible explanations for the lack of significant differences in storage scores across MLS task conditions in individuals with aphasia. First, it is possible that the two components of the task draw on separate resource pools, such that increasing demands on one of the components (processing) does not impact performance on the other (storage). This explanation is in line with the multi-component view of WM proposed by R.C. Martin and colleagues (1994, 1995). However, according to most resource theories, off-line processing (like the one required here) and storage draw on similar pools of resources since they both engage post-interpretive processes. Thus, even according to Caplan and Waters' (1996, 1999, 2004) theory of a distinct and independent WM specialized for syntactic processing, the length manipulation (affecting the number of propositions that must be maintained for accurate comprehension) places greater demands on the same general memory as that involved in recall of separately presented words. Overall, explanations regarding separate pools of resources do not have broad theoretical support and are inconsistent with the observed pattern of performance of individuals without aphasia for whom longer sentences negatively impacted recall.

Second, it may be that the ability to switch between processing and storage in the WM span task is the primary influence on WM capacity indices, rather than the difficulty of the task and characteristics of the linguistic stimuli. This argument is congruous with the explanation provided previously regarding the association between performance on the TLS and the MLS tasks. That is, if WM capacity is a domain-general ability to allocate processing resources or switch attention between two tasks (cf., Barrouillet et al., 2007; Cowan, 1999; Engle, Kane, et al., 1999; Engle, Tuholski, et al., 1999; Kane et al. 2001, 2004; Turner & Engle, 1989; Unsworth & Engle, 2008), then an increase in processing component difficulty should not directly impact recall performance (Conway & Engle, 1996), as long as the processing component is difficult enough to evoke controlled effortful processing (Bunting, 2006; Lepine, Barrouillet, & Camos, 2005).

A third plausible explanation is that increasing complexity and length of the linguistic stimuli did not elicit more effortful processing in individuals with aphasia. This could be because processing resources of individuals with aphasia were taxed to the maximum by the short and simple sentences to begin with or because they had difficulty monitoring their own performance, appropriately evaluating task demands, and, thus, allocating sufficient resources and implementing strategies to maintain comprehension across the varying conditions (Hula & McNeil, 2008; Murray, Holland, & Beeson, 1997; Tseng et al., 1993). It is also possible that participants with aphasia prioritized storage (recall) over processing. The fact that recall was not affected by longer sentences and, consequently, higher interference and longer retention intervals, could be explained by the possibility that participants with aphasia did not engage in active verbal rehearsal strategies, such that longer sentences had no negative impact on performance. All these "strategic" mechanisms would lead to a decline in processing scores as task difficulty increased while leaving recall performance unaffected.

4.3 Differences in performance between participants with and without aphasia

Participants with aphasia performed significantly less accurately on all components of the MLS task even when age and years of higher education were taken into account. While significant differences in processing scores could be attributed to language comprehension difficulties intrinsic to aphasia (cf., Benson, 1994; Grodzinsky, 1990), differences in storage scores cannot as easily be ascribed to a core linguistic deficit. The observed differences in performance on the recall components of WM tasks support the notion that the MLS task is sensitive to general reductions in processing resources, or limited capacity for controlled processing in people with aphasia with a broad range of linguistic deficits. Such sensitivity has been found using other complex span tasks administered to people with aphasia (Tompkins et al., 1994; Wright et al., 2003). In contrast to previous studies, validity of an MLS task as a measure of WM capacity in individuals without aphasia was demonstrated. This further reinforces the conclusion that the observed differences in recall performance between the two groups are due to variations in WM capacity rather than to influence of potentially confounding factors.

Interestingly, when WM scores of a subgroup of individuals with very mild comprehension deficits (AC scores ranging from 9.55 to 10) were compared to WM scores of participants without aphasia, significant differences in processing and storage scores still emerged. Moreover, in the current study several individuals had WAB-R scores within normal limits (as defined by Kertesz, 2007) yet all had reduced WM capacity relative to the control group as indexed via the MLS task. This indicates that, even when standardized tests are not sensitive to subtle linguistic deficits of people with mild aphasia, these individuals might still have reduced capacity for controlled processing that can be validly detected by the novel MLS task. The ability to index such reduced capacity is important; these remaining processing impairments might underlie the remnant language processing difficulties experienced by individuals with mild aphasia.

4.4 Dissociation between working memory capacity and language abilities in participants with aphasia

For the aphasia group overall, no significant relationship was observed between WM storage scores and scores on subtests of the WAB-R (Kertesz, 2007). Similar results were obtained by Ivanova and Hallowell (2012), Mayer and Murray (2012), and Christensen and Wright (2010), although in the latter two studies N-back tasks were used to index WM capacity. In the present study only the processing scores on the MLS task significantly correlated with auditory comprehension, repetition, naming, and the AQ of the WAB-R. The reason for the lack of association between WM storage and language scores may be methodological. Foremost, the WAB-R is not a detailed measure of general language abilities and it provides a limited assessment of comprehension abilities. A fine-grained analysis of comprehension may be critical for detecting a relationship between WM and language. WM capacity has been consistently shown to be related to performance on complex language comprehension tasks in people without aphasia (Baddeley, 2003; Conway & Engle, 1996; Conway et. al., 2005; Cowan, 1999; Just & Carpenter, 1992). Simple language tasks that require basic linguistic operations and direct retrieval of lexical items from the semantic system, such as naming of objects, single word comprehension, single word repetition, and production/

comprehension of short and simple sentences, do not rely heavily on WM; thus, they are to a great extent independent of available WM resources. With more complex language tasks, particularly tasks targeting receptive language abilities, an association may be detected between WM and language measures.

It may also be the case that combining all severity levels across people with aphasia obscures evidence of the differential influence of WM deficits on language abilities according to the severity of aphasia. This possibility is supported by results of the current study. A significant relationship was observed between WM capacity and AC scores for individuals with mild aphasia, while no significant relationship was detected for the moderately impaired group. Conversely, processing scores were related to AC abilities only in the group with moderate aphasia. Thus, in cases of moderate language impairment, linguistic deficits in of themselves may overshadow the potential impact of concomitant processing restrictions on language comprehension. In cases of milder deficits, these general reductions in processing capacity and efficiency may play a leading role in language comprehension. Such findings might be used to help reconcile opposing views of cognitive impairments in aphasia as either being causal or merely concomitant with language deficits. Given that, on one hand, individuals with very mild aphasia still had significantly lower WM storage scores compared to the control group, and, on the other hand, the two aphasia subgroups (mild and moderately impaired) did not differ substantially in terms of WM scores, the present findings lend support to the hypothesis that the observed cognitive deficits account for some language processing (especially language comprehension) difficulties.

4.5 The modified listening span task as a measure of working memory in aphasia

In sum, the current study supports the validity of a new MLS task as a measure of WM capacity in persons with and without aphasia. The novel MLS task showed high internal consistency, especially for storage measures, further supporting it as a reliable measure of WM deficits in aphasia. The task allows for differential control for length versus complexity of verbal stimuli and indexing of the relative influence of each, eliminates metalinguistic and reading requirements, enables control for complexity of processing components, and allows participants to respond with simple gestures or verbally to both components of the task. Additionally, performance on both the processing and the storage components can be indexed on per-item basis.

Given that no variation in recall performance was observed among the four conditions of the task in people with aphasia, employing just simple and short sentences appears adequate to evoke effortful processing in this population, regardless of the severity of individuals' language deficits. Use of simple and short sentences, which are most likely to be within the comprehension abilities of people with aphasia, makes it possible to ascertain that participants are attentive to the processing requirements of the task and can maintain a certain level of accuracy (e.g., Conway et al., 2005, implemented a cut-off of 85% accuracy for control participants). Further corroborating the validity of the short and simple condition of the MLS task for individuals with aphasia is the finding of a significant the relationship between storage scores and AC for this condition. Still, when the goal is to investigate characteristics of WM in people without cognitive or neurological impairments, using more complex sentences in a MLS task may be warranted because processing of such sentences requires more resources and may lead to a more fine-grained index of WM capacity.

4.6 Unresolved issues and directions for future research

In future investigations, STM storage, attention allocation, and speed of processing should be assessed separately to enable evaluation of the differential contribution of these factors to WM capacity as indexed via novel tasks. Presentation of processing and storage components, separately at first and then concurrently in a WM task, will help to detect trade-off patterns and elucidate whether any specific strategies determine recall performance. Future research should incorporate more detailed measures of general linguistic abilities, especially auditory comprehension. Furthermore, WM measures and their relationship to language processing abilities should be investigated within and across aphasia subtypes, and also in individuals with brain damage but without aphasia. It will be important to test the concurrent validity of the novel MLS task by comparing patterns of results with those from previous adaptations of the listening/reading complex span tasks and N-back tasks for individuals with aphasia. This will help to elucidate empirically the extent to which these measures index similar underlying phenomena and help evaluate the validity of previous findings on WM in aphasia.

Ultimately, it is vital to develop WM tasks appropriate for clinical assessment. Evaluating cognitive deficits in aphasia is important, especially in individuals with mild aphasia, where traditional linguistic measures might suggest a lack of deficit. The MLS task holds promise as a valid and suitable clinical assessment tool that will be helpful in treatment planning. For this purpose, large standardization samples are required, so that norms and other psychometric properties of the tasks may be established.

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Appendix A

Characteristics of Participants with Aphasia

#	A	G	Number of CVAs	Onset	Paresis/ Paralysis	AOS/ Dysarthria	Neuroimaging information	Aphasia type	Scores on the WAB-R subtests						MLS WM scores	
									SS	AVC	R	NaWF	AQ	Severity	ST	PR
a1	78	m	2	130	No	No	Left MCA infarct Left anterior temporal lobe, temporal operculum, posterior insular cortex, posterior frontal, parietal operculum	Anomic	15	9.5	8.8	8.5	83.5	mild	0.684	0.675
a2	67	f	1	110	No	No	n/a	Anomic	19	9.6	9.1	9.4	94.2	mild	0.603	0.938
a3	72	m	1	11	No	AOS	n/a	Anomic	18	9.3	8.0	9.9	90.3	mild	0.687	0.575
a4	22	m	1	22	No	No	n/a	Anomic/Conduction	12	7.2	6.2	7.1	65.0	moderate	0.913	0.5
a5	53	f	2	64	R side paralysis	AOS	n/a	Anomic	14	8.6	8.6	6.6	75.6	moderate	0.61	0.9
a7	51	f	1	98	No	No	n/a	Anomic	19	9.6	7.2	9.3	90.1	mild	0.893	0.4
a8	46	m	1	35	R side hemiparesis	AOS	n/a	Transcortical motor	13	9.4	7.4	7.8	75.2	moderate	0.687	0.9
a9	62	m	1	30	R side hemiparesis	No	n/a	Anomic	14	9.6	8.8	7.3	78.5	mild	0.676	0.875
a10	64	f	1	32	R side hemiparesis	AOS	Left MCA infarct Left frontalparietal	Transcortical motor	9	7.9	8.2	6.0	62.2	moderate	0.573	0.638
a11	60	f	1	50	R hemiparesis	AOS	n/a	Broca's	8	5.4	5.7	3.7	45.6	severe	0.728	0.513
a13	67	m	1	18	No	No	Left embolic CVA Left temporoparietal	Anomic	20	10.0	9.8	9.9	99.4	mild	0.812	0.9

									Scores on the WAB-R subtests						MLS WM scores	
#	A	G	Number of CVAs	Onset	Paresis/ Paralysis	AOS/ Dysarthria	Neuroimaging information	Aphasia type	SS	AVC	R	NaWF	AQ	Severity	ST	PR
a14	55	m	1	45	R paralysis	AOS	Left MCA infarct	Anomic	14	9.9	9.6	8.2	83.4	mild	0.899	0.925
a15	62	m	1	59	R paralysis/hemiparesis	Dysarthria, poor breath control and voice quality	n/a	Anomic	15	10.0	9.4	10.0	88.8	mild	0.833	0.938
a16	46	m	2	151	R hemiparesis	AOS	Left large MCA infarct Left frontal, temporal and parietal	Anomic	19	9.1	9.1	8.4	91.2	mild	0.781	0.788
a18	45	f	1	10	R side paresis	AOS	Left MCA hemorrhage Left inferior frontal, inferior parietal, anterior temporal (gliosis and encephalomalacia)	Anomic	16	7.3	8.6	5.6	75.0	moderate	0.553	0.95
a19	60	m	1	125	R side paresis	No, phonation problems	Had a left CVA infarct following removal of a tumor that extended from his neck to the top of his head. Left basal ganglia/ insula infarct, also extends to the inferior frontal lobule with middle frontal gyrus white matter changes.	Anomic	18	10.0	9.9	8.9	93.6	mild	0.806	0.725
a21	59	m	1	74	R leg paresis, R arm paralysis	AOS	Left carotid artery occlusion	Transcortical motor	13	9.0	7.6	7.7	74.5	moderate	0.782	0.613
a22	57	m	1	35	R paresis	dysarthria	n/a	Anomic	15	9.4	9.0	9.3	85.4	mild	0.768	0.875
a24	66	m	1	15	No	No	n/a	Anomic	19	9.1	9.3	8.7	92.1	mild	0.742	0.888
a25	58	f	2	101	R leg paresis, R arm paralysis	AOS	n/a	Broca's	9	6.9	1.7	5.0	45.1	severe	0.753	0.4
a26	70	m	1	66	No	Dysarthria	CVA following carotid artery endectomy	Anomic	19	9.6	10.0	9.1	95.4	mild	0.701	0.888
a27	45	f	1	47	No	AOS	n/a	Anomic	15	9.9	7.7	8.7	82.5	mild	0.828	0.825
a28	41	m	1	20	No	AOS	Left ischemic CVA, with hemorrhagic conversion Left temporal and frontal	Broca's	11	6.3	3.9	5.0	52.4	moderate	0.684	0.363
a29	59	m	1	275	R hemiparesis	AOS, mild dysarthria	Left MCA and internal carotid hemorrhage (due to aneurism) Large left frontaltemporal lesion	Broca's	12	7.8	4.0	4.7	57.0	moderate	0.826	0.525
a31	60	f	1	68	R hemiparesis	No	n/a	Anomic/Conduction	12	8.7	6.4	8.5	71.2	moderate	0.694	0.575
a32	32	f	1	23	R hemiparesis arm and leg	AOS	Left parietal infarction and dural sinus trombosis/ hematoma Left temporal, occipital, and posterior parietal	Anomic	13	8.0	7.5	7.6	72.1	moderate	0.899	0.488
a33	60	m	2	38	R arm weaker	AOS, dysarthria	Anterior left MCA infarct Left frontal operculum region The second incident, which was a TIA, led to cerebellar lesions.	Anomic	15	10.0	9.1	8.8	85.8	mild	0.709	0.988

Note. A = Age; G = Gender; Onset = Months past onset (if multiple CVAs time from the first CVA is indicated); WAB-R subtests: SS = spontaneous speech; AVC = auditory verbal comprehension; R = repetition; NaWF = naming and word finding.

Aphasia type is indicated according to the WAB-R classification.

WM scores: ST=storage score; PR=processing score.

Appendix B

Verbal stimuli of the modified listening span task

Short and simple condition

1. The girl is leaving the woman.
2. The man is calling the girl.
3. The man is following the woman.
4. The boy is carrying the girl.
5. The girl is serving the man.
6. The woman is painting the boy.
7. The boy is watching the man.
8. The woman is driving the man.
9. The girl is pulling the boy.
10. The woman is feeding the girl.
11. The man is hitting the woman.
12. The boy is pushing the girl.
13. The man is touching the girl.
14. The man is washing the boy.
15. The girl is helping the woman.
16. The boy is finding the woman.
17. The boy is dressing the man.
18. The girl is kicking the boy.
19. The woman is kissing the man.
20. The woman is burying the boy.

Short and complex condition

1. The woman is called by the girl.
2. The girl is followed by the man.
3. The woman is carried by the man.
4. The girl is left by the man.
5. The man is painted by the girl.
6. The boy is watched by the woman.
7. The man is driven by the boy.

8. The man is served by the woman.
9. The boy is hit by the girl.
10. The girl is pushed by the woman.
11. The woman is washed by the man.
12. The girl is helped by the boy.
13. The girl is fed by the man.
14. The boy is pulled by the man.
15. The woman is kissed by the girl.
16. The woman is touched by the boy.
17. The man is kicked by the boy.
18. The boy is buried by the girl.
19. The man is found by the woman.
20. The boy is dressed by the woman.

Long and simple condition

1. The woman in grey pants is leaving the little girl with black hair.
2. The girl with the pony-tail is calling the tall man in the sweater.
3. The woman in gray pants is following the tall man with short hair.
4. The little girl in the dress is carrying the boy with short hair.
5. The young man in long gray pants is serving the girl with blonde hair.
6. The boy with short hair is painting the young woman in the long-sleeve shirt.
7. The man in the white sweater is watching the little boy with short hair.
8. The young man with a smile is driving the woman with dark hair.
9. The little boy with black hair is pulling the girl in the bathing suit.
10. The small girl with blonde hair is feeding the woman in the gray shirt.
11. The young woman in the shirt is hitting the man with dark hair.
12. The girl with dark hair is pushing the small boy in the long-sleeve shirt.
13. The girl with blonde hair is touching the tall man in the sweater.
14. The little boy in the gray sweater is washing the man with dark hair.
15. The young woman in the gray shirt is helping the girl with short hair.
16. The woman in the black skirt is finding the small boy in the tee-shirt.
17. The man in gray shorts is dressing the little boy with blonde hair.

18. The little boy with short hair is kicking the girl with dark hair.
19. The man in the gray sweater is kissing the young woman in the dark skirt.
20. The small boy with black hair is burying the woman with the pony-tail.

Long and complex condition

1. The little girl with black hair is called by the woman in grey pants.
2. The tall man in the sweater is followed by the girl with the pony-tail.
3. The tall man with short hair is carried by the woman in gray pants.
4. The boy with short hair is left by the little girl in the dress.
5. The girl with blonde hair is painted by the young man in long gray pants.
6. The young woman in the long-sleeve shirt is watched by the boy with short hair.
7. The little boy with short hair is driven by the man in the white sweater.
8. The woman with dark hair is served by the young man with a smile.
9. The girl in the bathing suit is hit by the little boy with black hair.
10. The woman in the gray shirt is pushed by the small girl with blonde hair.
11. The man with dark hair is washed by the young woman in the shirt.
12. The small boy in the long-sleeve shirt is helped by the girl with dark hair.
13. The tall man in the sweater is fed by the girl with blonde hair.
14. The man with dark hair is pulled by the little boy in the gray sweater.
15. The girl with short hair is kissed by the young woman in the gray shirt.
16. The small boy in the tee-shirt is touched by the woman in the black skirt.
17. The little boy with blonde hair is kicked by the man in gray shorts.
18. The girl with dark hair is buried by the little boy with short hair.
19. The young woman in the dark skirt is found by the man in the gray sweater.
20. The woman with the pony-tail is dressed by the small boy with black hair.

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Highlights

- We developed a novel modified listening span task to measure working memory in adults with aphasia specifically designed to overcome limitations of existing measures.
- We evaluated performance of people with and without aphasia using this novel measure of working memory
- The novel task demonstrated high concurrent validity with an established measure of working memory capacity in adults without aphasia.
- As expected, participants with aphasia performed significantly worse on the task compared to control participants without any neurological disorder.
- Results support the feasibility and validity of using the novel task to assess working memory in adults with and without aphasia.

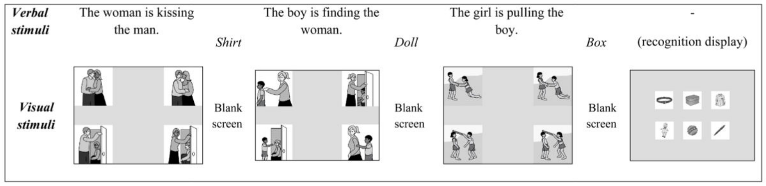

Figure 1.
Example of a set from the modified listening span task (set size three, short and simple condition).

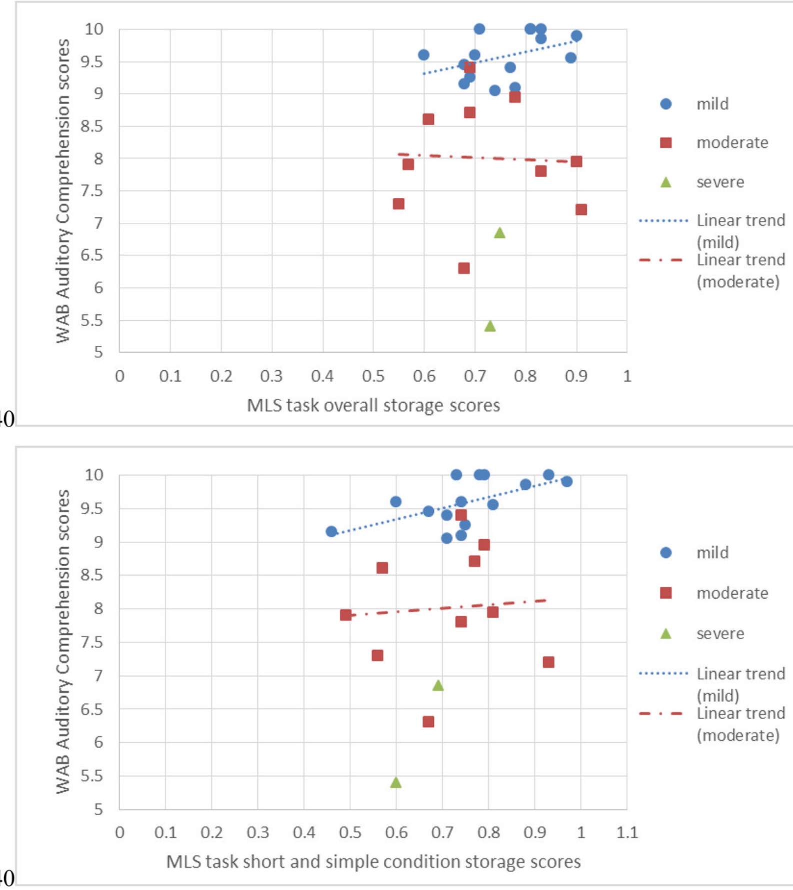

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Figure 2.

Scatterplots and linear trends between MLS storage scores (overall and the short and simple condition) and WAB Auditory Comprehension subtest scores by aphasia severity.

Table 1

Sentences Used in the Four Conditions of the Modified Listening Span Task

Condition	Length (number of syllables)	Complexity (type of syntactic construction)	Example
Short and Simple	7 – 9	Active	The woman is kissing the man.
Short and Complex	7 – 9	Passive	The man was kissed by the woman.
Long and Simple	15 – 18	Active	The young woman in the dark skirt is kissing the man in the grey sweater.
Long and Complex	15 – 18	Passive	The man in the grey sweater is kissed by the young woman in the dark skirt.

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Table 2

Descriptive Statistics for Working Memory (WM) Scores on the Traditional Listening Span and on the Modified Listening Span Tasks

WM tasks		WM scores	Participants without aphasia (N = 33)					Participants with aphasia (N = 27)				
			M	**SD**	**Min**	**Max**	**RC**	**M**	**SD**	**Min**	**Max**	**RC**
Traditional listening span task		ST	.77	.12	.49	.97	.748	-	-	-	-	-
		PR	.98	.03	.90	1.00	.255	-	-	-	-	-
Conditions of the Modified Listening Span Task	Short and Simple	ST	.92	.08	.71	1.00	.651	.73	.13	.46	.97	.824
		PR	1.00	.01	.95	1.00	−.080	.83	.16	.40	1.00	.753
	Short and Complex	ST	.93	.07	.74	1.00	.586	.77	.11	.50	1.00	.850
		PR	.99	.02	.90	1.00	.265	.66	.29	.00	1.00	.907
	Long and Simple	ST	.90	.08	.65	1.00	.676	.75	.09	.57	.91	.805
		PR	.99	.02	.90	1.00	.087	.77	.20	.40	1.00	.813
	Long and Complex	ST	.90	.09	.69	1.00	.569	.74	.14	.54	.97	.799
		PR	.98	.03	.85	1.00	.115	.64	.27	.25	1.00	.896
	Overall	ST	.92	.07	.74	1.00	.878	.75	.10	.55	.91	.950
		PR	.99	.01	.95	1.00	.362	.72	.20	.36	.99	.945

Note. RC = reliability coefficient (Cronbach's alpha); WM scores: ST = storage score; PR = processing score.

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Table 3

Correlations Between Working Memory (WM) Scores on the Traditional Listening Span and the Modified Listening Span Tasks

	WM scores	Modified listening span				
		Short and Simple	**Short and Complex**	**Long and Simple**	**Long and Complex**	**Overall**
Traditional listening span	ST	.525**	.736**	.578**	.729**	.732**
	PR	.367*	−.124	.165	.023	.142

Note. WM scores: ST=storage score; PR=processing score.

* $p < .05$,

** $p < .01$.

Table 4

Repeated Measures ANOVA for Working Memory (WM) Scores on the Modified Listening Span Task

WM scores	Factors	Participants without aphasia					Participants with aphasia				
		df	*MS*	*F*	*p*-value	η^2	*df*	*MS*	*F*	*p*-value	η^2
ST	Length	1, 32	.022	12.271	.001	.277	1, 26	.000	.088	.769	.003
	Complexity	1, 32	.001	.580	.452	.018	1, 26	.006	.942	.341	.035
	Length x Complexity	1, 32	.000	.070	.794	.002	1, 26	.018	4.324	.048	.143
PR	Length	1, 32	.001	1.727	.198	.051	1, 26	.047	4.924	.035	.159
	Complexity	1, 32	.002	4.000	.054	.111	1, 26	.585	18.406	.000	.414
	Length x Complexity	1, 32	.000	1.198	.282	.036	1, 26	.005	.293	.593	.011

Note. WM scores: ST=storage score; PR=processing score.

Table 5

Univariate General Linear Model Analysis of Working Memory (WM) Scores Between Participants with and without Aphasia

Conditions of the Modified Listening Span Task	**WM scores**	***df***	***MS***	***F***	***p*-value**	η^2
Short and Simple	ST	1, 56	.495	55.721	<.001	.499
	PR	1, 56	.404	33.158	<.001	.372
Short and Complex	ST	1, 56	.328	47.451	<.001	.459
	PR	1, 56	1.542	40.609	<.001	.420
Long and Simple	ST	1, 56	.277	45.955	<.001	.451
	PR	1, 56	.763	44.505	<.001	.443
Long and Complex	ST	1, 56	.304	33.420	<.001	.374
	PR	1, 56	1.727	50.834	<.001	.476
Overall	ST	1, 56	.347	66.738	<.001	.544
	PR	1, 56	1.033	56.024	<.001	.500

Note. WM scores: ST=storage score; PR=processing score.

Table 6

Correlations Between Western Aphasia Battery-Revised and Working Memory (WM) Scores

Conditions of the Modified Listening Span Task	WM scores	Spontaneous speech	Auditory verbal comprehension	Repetition	Naming	Aphasia Quotient
Short and Simple	ST	.193	.345	.057	.442*	.260
	PR	.684**	.722**	.723**	.688**	.776**
Short and Complex	ST	.045	.118	−.048	.224	.078
	PR	.276	.504**	.621**	.296	.441*
Long and Simple	ST	.012	.138	−.146	.098	.011
	PR	.489**	.800**	.774**	.647**	.706**
Long and Complex	ST	−.001	−.033	−.164	.008	−.048
	PR	.475*	.593**	.734**	.435*	.607**
Overall	ST	.075	.163	−.086	.227	.090
	PR	.515**	.719**	.802**	.548**	.689**

Note. WM scores: ST=storage score; PR=processing score.

* $p < .05$,

** $p < .01$.