Introduction

Deficits in working memory (WM) are a critical subset of non-linguistic deficits in aphasia (Murray, Ramage, & Hooper, 2001; Wright & Shisler, 2005). Significant differences between WM capacity of individuals with and without aphasia (Tompkins, Bloise, Timko, & Baumgaertner, 1994; Wright, Newhoff, Downey, & Austermann, 2003) and significant correlations between WM and general language measures (Caspari, Parkinson, LaPointe, & Katz, 1998; Wright et. al., 2003; Wright, Downey, Gravier, Lover, & Shapiro, 2007) have been demonstrated. Further study of the role of WM in aphasia is important, for better understanding of the non-linguistic aspects of aphasia, developing valid and reliable assessment methods, and providing optimal treatment while taking non-linguistic factors into account. Unfortunately, the study of WM in aphasia is fraught with methodological limitations, largely due to the difficulty of controlling for potential confounds in design of WM tasks and associated performance measures (cf., Ivanova & Hallowell, 2008).

In the current study we describe a novel WM task – the modified listening span (MLS). This task was developed with the aim of circumventing confounds associated with existing WM tasks and measures in aphasia. The sentence-picture matching task, used for the processing part of the task, is more natural in terms of everyday language use and relies less on intact metalinguistic skills in contrast to true/false judgments. In contrast to random comprehension questions it provides a more accurate and detailed index of performance on the processing component of the WM task. Use of sentences of varying length and complexity allowed investigation of the differential impact of these factors on performance of persons with and without aphasia. Additionally, the task was constructed so that participants could respond either with simple gestures or verbally, to both processing and recall components. The aim of this paper is to delineate and compare patterns of performance of participants with and without aphasia on different conditions of the MLS task.

Methods

Individuals with aphasia due to stroke (n=27) and individuals without language, cognitive, or neurological impairments (n=33) participated in the study.

In the MLS task participants were asked to listen to sentences and remember a separate set of words for subsequent recognition at the same time. Length and complexity of presented sentences were manipulated separately, creating conditions with: (a) short and simple (active); (b) short and complex (passive); (c) long and simple; and (d) long and complex sentences. All sentences in the task were semantically and syntactically plausible, and were semantically reversible (see Table 1 for examples of sentences).

Along with the auditory presentation of each sentence, multiple-choice image arrays were presented. Each array consisted of four pictures: one target and three foils. Participants were asked to point to the image that best matched the sentence.

Items to be remembered were separate words presented after each sentence. The recall component of the task was changed to rely solely on recognition. At the end of each sentence set an array of pictures including target (representing words to be remembered) and foil images were presented for recognition. In Figure 1 an example of a set from the task is provided.

Sentences were presented in sets of 2 to 6 in ascending order. One set of each set size was presented within each condition. Verbal stimuli were prerecorded and digitized. Experimental stimuli were presented via computer screen.

The following measures (computed for each condition) were used to index performance:

- Storage score. Items were scored as proportion of correctly recalled/recognized elements per set; for the final score a mean of these proportions was calculated (Conway et al., 2005).
- Processing score. Expressed as the proportion of items for which the target picture was correctly selected.

Results

In order to investigate differences across conditions of the MLS task, a repeated measures ANOVA was performed on the processing and storage scores for the four conditions of the task (see Table 2).

Significant F-tests were followed up with pair-wise comparisons. For participants without aphasia only the difference in storage scores between the short and complex and long and simple condition was significant, t (32) = 2.99, p = .005. For participants with aphasia processing scores in the short and simple condition were significantly higher than in the short and complex (t (26) = 3.1, p = .005) and in the long and complex conditions (t (26) = 4.63, p < .001). Also, processing scores in the long and simple condition were significantly higher than in the short and complex (t (26) = 2.82, p = .009) and in the long and complex conditions (t (26) = 4.28, p < .001).

Further differences in WM scores between participants with and without aphasia were explored using generalized linear models analysis, with age and years of higher education taken as covariates (see Table 3).

Conclusion

MLS task performance was significantly different for participants with aphasia compared to those without aphasia in terms of both storage and processing scores. At the same time, different patterns of performance were observed within each group.

For participants without aphasia impact of length of linguistic stimuli was detected only on storage scores. Length of sentences negatively affected recall. It is likely that increased verbal interference and longer retention intervals in trials with longer sentences led to significantly lower recall scores. WM scores were not significantly influenced by complexity of sentence stimuli.

Performance of participants with aphasia was negatively affected by complexity and length of sentences only on the processing component of the task. The variation in processing scores was anticipated, especially inasmuch as comprehension deficits are prevalent in aphasia (Berndt, Mitchum, & Haendiges, 1996; Caplan & Waters, 1999; Caplan, Waters, & Hildebrandt, 1997).

Storage scores were not significantly influenced by variations in linguistic length and complexity. There are several plausible explanations for this. First, the two components of the task might draw on separate pools of resources, such that increasing processing demand on one of the components (processing) does not impact performance on the other (storage). This explanation is consistent with Caplan and Water's (1996, 1999, 2004) theory of working memory specialized for syntactic processing. A second possible explanation is that the individuals with aphasia did not exert more effort as the complexity and length of the linguistic stimuli increased. This is consonant with the experimental literature demonstrating that individuals with aphasia have difficulty monitoring their own performance, appropriately evaluating task demands, and, thus, allocating a sufficient amount of resources for successful completion of the task (Murray, Holland, & Beeson, 1997; Tseng, McNeil, & Milenkovic, 1993). A third potentially viable account is that processing resources of individuals with aphasia were taxed to the maximum by the short and simple sentences to begin with, such that, increasing length and complexity of the sentences did not further impact recall.

Based on the findings of the current study, it is sufficient to use active and short sentences for the processing component of the MLS task with participants with aphasia, as it is effective in evoking effortful processing. In sum, the feasibility of using of a novel task to assess WM in individuals with and without aphasia has been empirically demonstrated. Performance on the task according to both dependent measures reliably differentiated between the two groups, supporting the criterion validity of the novel measure.

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Tables and Figures

Table 1
Sentences Used in the Four Conditions of the MLS Task

Condition	Length (number of words)	Complexity (type of syntactic construction)	Example
Short and Simple	6 – 7	Active	The woman is kissing the man.
Short and Complex	6 – 7	Passive	The man was kissed by the woman.
Long and Simple	14 – 17	Active	The young woman in the dark skirt is kissing the man in the grey sweater.
Long and Complex	14 – 17	Passive	The man in the grey sweater is kissed by the young woman in the dark skirt.

Table 2
Repeated Measures ANOVA for WM Scores on the MLS Task for Participants with and without Aphasia

WM scores	Participants without aphasia (N=33)				Participants with aphasia (N=27)			
	df, df error	*F*	*p*-value	η^2	*df, df error*	*F*	*p*-value	η^2
ST	3, 96	4.032	.01	.112	3, 78	1.577	.4	.057
PR	2.313, 74.03*	2.453	.068	.071	2.043, 53.12*	10.789	<.001	.293

Note. WM scores: ST=storage score; PR=processing score.
* Degrees of freedom were adjusted using the Greenhouse-Geisser correction for non-sphericity.

Table 3
Generalized Linear Models Analysis of WM Scores between Participants with and without Aphasia with Age and Years of Education as Covariates

Conditions of the MLS task	WM scores	*B*	*SE B*	*Wald* X^2	*p*-value
Short and Simple	ST	.186	.024	59.7	<.001
	PR	.168	.028	35.53	<.001
Short and Complex	ST	.152	.021	50.84	<.001
	PR	.328	.05	43.51	<.001
Long and Simple	ST	.139	.02	49.24	.019
	PR	.231	.034	47.68	<.001
Long and Complex	ST	.146	.024	35.81	<.001
	PR	.348	.047	54.47	<.001

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

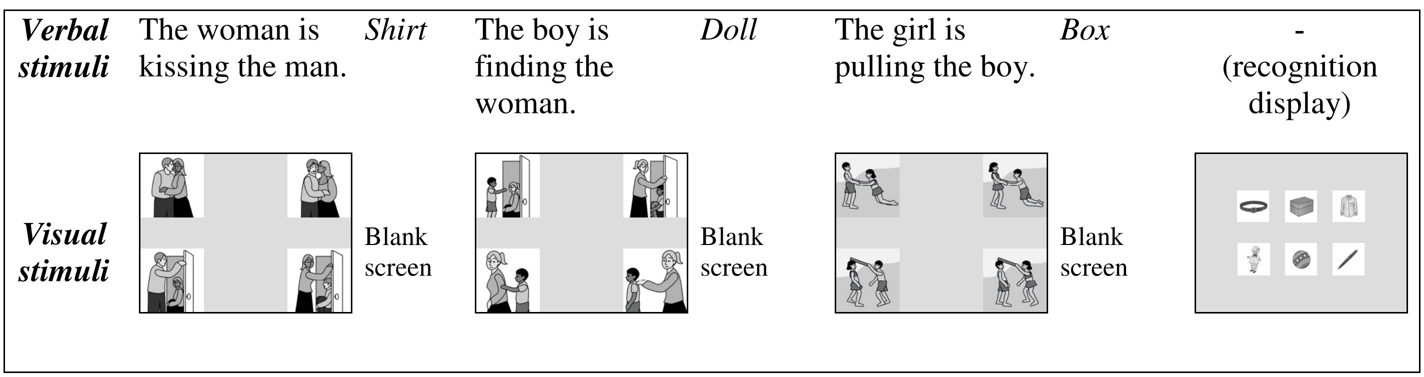

Figure 1. Example of a set from the MLS task (set size three, short and simple condition).