INTRODUCTION

Deficits in working memory (WM) and attention have been associated with aphasia (Heuer & Hallowell, 2009; Hula & McNeil, 2008; Ivanova & Hallowell, 2011; Murray, 1999; Wright & Shisler, 2005). Some authors suggest that WM and attention deficits are not only concomitant with the language deficits of people with aphasia but that they actually contribute to the very nature of those deficits (McNeil & Pratt, 2001). Working memory is 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). Thus, WM may be regarded as a capacity for storage of information during processing or in the face of ongoing interference. Attention is the process of selectively focusing on specific stimuli while excluding competing stimuli. It is viewed as a limited cognitive resource that can only be distributed among a fixed number of tasks, depending on task demands (Kahneman, 1973). Intact attention relies on sufficient capacity and efficient allocation. Based on those definitions, there is great overlap between the constructs of WM and attention. This overlap is also apparent across theoretical models of attention and WM.

In Baddeley's multi-component model of WM the control system (the central executive) represents a pool of limited attentional resources (Baddeley & Logie, 1999). The central executive allocates and coordinates processing resources between modality-specific buffers. Just and Carpenter (1992) regard WM as a unitary capacity that is available for both storage and concurrent processing. Caplan and Waters (1999) describe a specific WM for online processing of syntactic information along with a more general WM for offline language processing. Neither Just and Carpenter nor Caplan and Walters explicitly address attention in their models. In more recent theories, WM has been considered in terms of its domain-free capability. Empirical studies have confirmed a vital relationship between attention and WM functions (Conway, Moore, & Kane, 2009; Cowan, 1999; Engle, Tuholski, et al., 1999; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2000; Turner & Engle, 1989). Different types of attention, including attention allocation (Engle, Kane et al., 1999; Kane et al. 2004), focus of attention (Cowan et al., 2005; Oberauer, 2002), attentional switching (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Garavan, 1998; Towse, Hitch, & Hutton, 2000), and sustained attention (Magimairaj, 2010), have been described. However, the relationship between these types of attention and WM is not well understood.

It remains unclear as to whether WM deficits and attention deficits are independent cognitive impairments intrinsic to aphasia or whether these are different but interrelated aspects of a singular cognitive impairment. The lack of clear evidence that attention and WM are separable conceptually or empirically, and the lack of agreement about the degree to which each or both contribute to the severity of language deficits in aphasia, make this is a fertile area for further research. In this study we investigated whether the ability to allocate attention is related to WM capacity in adults with and without aphasia.

METHODS

Twenty-three adults with aphasia participated. Detailed participant characteristics will be summarized. Aphasia was assessed with the Western Aphasia Battery (WAB-R, Kertesz, 2007). Thirty individuals without language, cognitive, or neurological deficits and who passed a mental status screening (Mini Mental Status Examination; Folstein, Folstein, & McHugh, 1975) served as controls. All participants passed vision and hearing screenings.

Experimental tasks administered were: (a) a modified listening span (MLS) task (Ivanova & Hallowell, 2009, 2011); (b) an eye-tracking WM task (Ivanova & Hallowell, 2010); and (c) an attention allocation task (Heuer & Hallowell, 2009). In the MLS task participants were asked to match sentences of varying length and complexity (active and passive) to pictures and also to remember a separate set of words for subsequent recognition. The eye-tracking WM task was similar to the MLS task except that participants had to remember symbols/colors and performance was indexed via participants' eye fixations, monitored and recorded at 60 Hz using a remote pupil center/corneal reflection system. Eye fixations were also monitored during attention allocation tasks: (a) a visual search task in which participants were trained to find a target in a display including one target and three nontarget foils, and (b) a listening comprehension task, in which a verbal stimulus was presented, followed by a multiple-choice comprehension task display. In the single-task condition only the visual search task was presented. In the dual-task condition participants were presented simultaneously with the visual search task and the verbal stimulus for the listening comprehension task (See Figures 1 – 3 for examples of stimulus sets). These tasks, each previously validated, were designed explicitly to help reduce many of the potential confounds in assessment of WM or attention.

RESULTS

Visual search performance in the single-task condition was significantly related to WM capacity for control participants according to most measures, but was significantly related to only one of the WM measures for participants with aphasia (Table 1).

Visual search performance in the dual-task condition was related to WM capacity for controls as indexed through the eye-tracking WM task, and related to WM capacity in participants with aphasia as indexed through the MLS condition with short and simple sentences (Table2).

The degree of decrement in performance from the single- to dual-task attention allocation condition was not significantly related to WM capacity for either group for either simple or complex stimuli (Table 3). The only exception was that eye-tracking WM storage scores were significantly correlated with the decrement in single-to dual-task scores for the trials involving simple stimuli.

The degree of decrement in performance from simple to complex visual stimuli (a) within the single-task condition and (b) within the dual-task condition was not significantly related to WM capacity for either group (Table 4).

DISCUSSION

When comparing single-task attention allocation performance with each of the WM measures, no significant correlations were observed in individuals with aphasia. However, dual-task attention allocation measures were significantly correlated with WM measures. Individuals with aphasia may have tended to exceed their WM capacity with an increase in task demands from single-to dual task.

Overall, there is no clear pattern of results suggesting a consistent correspondence between attention allocation and WM measures. This is surprising, given the conceptual relatedness of the two constructs and given the opinion of many aphasiologists that the ability to allocate attention directly impacts WM capacity. It may be the case that the constructs of attention and WM are reflected differentially when indexing them with the types of measures used here. It is also possible that other types of attention, such as focus of attention, may be more closely related to WM capacity.

Further analyses taking into account overall aphasia severity and severity of comprehension deficits may yield more insight into the complex relationship between WM and attention. Our sample was intentionally heterogeneous in terms of type of aphasia and severity. A more consistent relationship between WM capacity and attention allocation may be found when comparing individuals of a specific severity level or with specific language deficits.

Further research entailing measures of WM and attention that reduce or eliminate verbal processing demands and minimize reliance on overt spoken or limb-motor responses may help to elucidate the relationship of WM and attention in aphasia.

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FIGURES and TABLES

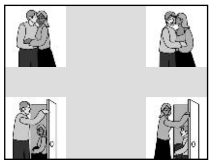
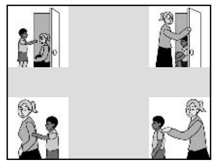
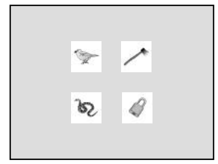
Verbal stimuli	The woman is kissing the man.	*Bird*	The boy is finding the woman.	*Lock*	(recognition display)
Visual stimuli		Blank screen		Blank screen	
Duration of presentation	Until participant gives a response (points to a picture)	2 sec.	Until participant gives a response (points to a picture)	2 sec.	Until participant gives a response (points to images)

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

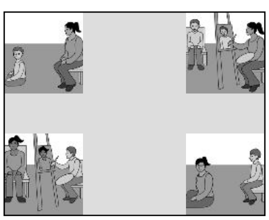
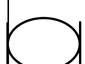
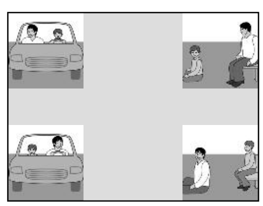
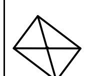
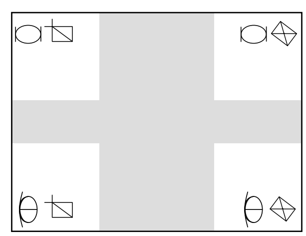
Verbal stimuli	The boy is watching the woman.	-	The man is driving the boy.	-	(recognition display)
Visual stimuli					
Duration of presentation	Twice the duration of the verbal stimuli plus two seconds	2 sec.	Twice the duration of the verbal stimuli plus two seconds	2 sec.	Number of items to be recalled times 2.5 seconds (in this case 5 seconds)

Figure 2. Example of a sequence of multiple-choice arrays in the eye-movement working memory task (set size two, symbols).

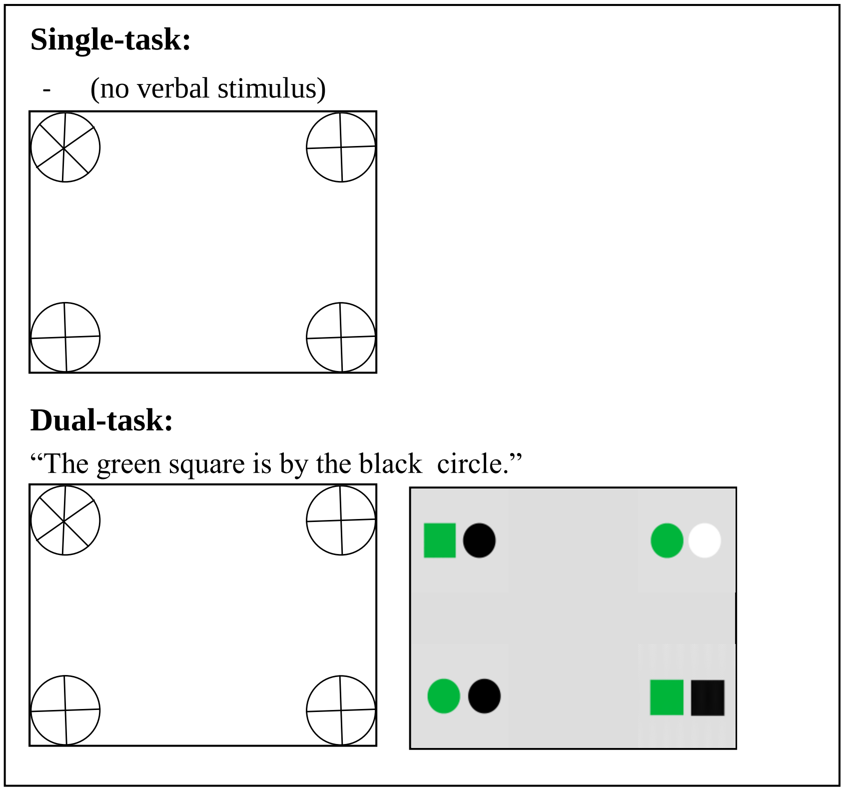


Figure 3. Example of a sequence of multiple-choice arrays in the attention allocation task (single- and dual-task conditions).

Table 1
Correlations between Working Memory Storage Scores and Proportion of Fixation Duration on the Target Image in the Visual Search Task in the Single-task Condition for Participants With and Without Aphasia

		Participants without aphasia			Participants with aphasia		
		MLS storage score (overall)	MLS storage score – short and simple	EMWM storage score	MLS storage score	MLS storage score – short and simple	EMWM storage score
Proportion of Fixation Duration on Target	overall	.444*	.314	.653**	.349	.418	.159
	simple stimuli	.427*	.294	.652**	.347	.326	.07
	complex stimuli	.443*	.32	.625**	.293	.423*	.208

Note. MLS= Modified listening span task; EMWM=Eye movement working memory task.
* $p < .05$, ** $p < .01$.

Table 2

Correlations between Working Memory Storage Scores and Proportion of Fixation Duration on the Target Image in the Visual Search Task in the Dual-task Condition for Participants With and Without Aphasia

		Participants without aphasia			Participants with aphasia		
		MLS storage score (overall)	MLS storage score – short and simple	EMWM storage score	MLS storage score	MLS storage score – short and simple	EMWM storage score
Proportion of Fixation Duration on Target	overall	.244	.386*	.461*	.392	.498*	.364
	simple stimuli	.24	.457*	.339	.334	.533**	.401
	medium stimuli	.214	.319	.476**	.354	.374	.206
	complex stimuli	.246	.345	.502**	.384	.428*	.385

Note. *MLS= Modified listening span task; EMWM=Eye movement working memory task.*
** p < .05, ** p < .01.*

Table 3

Correlations between Working Memory Storage Scores and Attention Allocation Measures for Participants With and Without Aphasia

		Participants without aphasia			Participants with aphasia		
		MLS storage score (overall)	MLS storage score – short and simple	EMWM storage score	MLS storage score	MLS storage score – short and simple	EMWM storage score
Decrement in attention allocation from single- to dual-task condition	overall	.1	-.157	.038	-.16	-.225	-.311
	simple stimuli	.066	-.235	.126	-.147	-.371	-.415*
	complex stimuli	.106	-.115	-.020	-.094	-.011	-.187

Note. *MLS= Modified listening span task; EMWM=Eye-tracking working memory task.*
** p < .05*

Table 4

Correlations between Working Memory Storage Scores and Attention Allocation Measures for Participants With and Without Aphasia

		Participants without aphasia			Participants with aphasia		
		MLS storage score (overall)	MLS storage score – short and simple	EMWM storage score	MLS storage score	MLS storage score – short and simple	EMWM storage score
Decrement in attention allocation from simple to complex stimuli	single-task condition	.028	-.016	.160	-.014	-.202	-.182
	dual-task condition	.034	.241	-.160	.088	.326	.216

Note. *MLS= Modified listening span task; EMWM=Eye movement working memory task.*

* *p* < *.05*