Journal of Neurolinguistics xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

Working memory in aphasia: Peeling the onion☆

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ARTICLE INFO

Keywords:
Working memory
Aphasia
Attention
Executive control

ABSTRACT

Compared to neurologically healthy adults, persons with aphasia (PWA) demonstrate impaired performance on working memory (WM) tasks. These deficits in WM are thought to underlie language processing problems in PWA. However, most studies use WM tasks that are verbal in nature, making it difficult to determine if these deficits are due to domain-general attentional processes related to WM or domain-specific verbal abilities. The purpose of the current study was to examine WM performance in PWA and healthy controls using verbal and spatial WM tasks. Additionally, this study investigated the relationship among WM performance and performance on short-term memory and domain-general attentional tasks. Fourteen PWA and 13 control participants completed verbal and spatial *n*-back tasks, the Flanker arrows task, and forward digit and spatial span tasks. The results revealed that the PWA performed worse than the control participants on the verbal tasks, but there were no group differences on the spatial tasks. Further, PWA showed significantly greater conflict and interference effects on the Flanker arrows task than control participants. These findings suggest that although WM deficits are primarily evident in the verbal domain in PWA, they are not solely the result of domain-specific verbal deficits; the ability to inhibit irrelevant information may contribute to WM deficits in PWA.

People with aphasia (PWA) display impairments on both attention (see Murray, 1999 for review) and working memory tasks (see Wright & Fergadiotis, 2012 for review). Working memory (WM) is the ability to maintain information in an active state while manipulating and using that information for mental operations. Most models consider WM to include both domain-general attentional and domain-specific processing and storage components (e.g. Baddeley & Hitch, 1974; Baddeley, 2000; Cowan, 1999; Engle, Tuholski, Laughlin, & Conway, 1999), although they differ in their emphasis on these processes.

1. Working memory frameworks

Although WM deficits have been well documented in people with aphasia (PWA; Caspari, Parkinson, LaPointe, & Katz, 1998; Christensen & Wright, 2010; Murray, 2004; Tseng, McNeil, & Milenkovic, 1993; Wright, Newhoff, Downey, & Austerman, 2003; Wright & Shisler, 2005; Ivanova, Dragoy, Kuptsova, Ulicheva, & Laurinvavichyute, 2015), and attentional impairments reported (Laures, 2005; LaPointe & Erickson, 1991; Hula & McNeil, 2008; Murray, 2012; Murray, Holland, & Beeson, 1997a; Murray, Holland, & Beeson, 1997b; McNeil, Odell & Tseng, 1991; Tseng et al., 1993; Villard & Kiran, 2015), the relative contribution of domain-general attentional processes versus domain-specific verbal storage (i.e. verbal STM) to WM performance has not been systematically

☆ This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
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https://doi.org/10.1016/j.jneuroling.2018.02.001
Received 15 July 2017; Received in revised form 1 February 2018; Accepted 1 February 2018
0911-6044/

investigated. One model of working memory that may be used to investigate WM is aphasia is Baddeley's (2000) model. Following Baddeley's model of WM (2000), verbal and visual-spatial information are stored separately in phonological and spatial short-term buffers. The functions of these short term memory (STM) systems, i.e., the phonological loop and visuospatial sketchpad, are to maintain the phonological and visuospatial representations, respectively. Although these two buffers are separate, they interact with an episodic buffer that is capable of linking information into meaningful chunks for long-term storage. Finally, the model also includes a central executive system that directs and monitors information storage and manipulation within the phonological and visuo-spatial buffers. This executive component is domain-general, limited in capacity, and corresponds closely with the executive/attentional control system specified in models of attention which have been readily applied to studies of PWA (e.g. Kahneman, 1973; Norman & Shallice, 1986).

Although Baddeley's Multicomponent model highlights several different areas that could contribute to WM impairments, other models emphasize central executive processes. According to Engle et al. (1999), who also view WM as a hierarchically organized system of STM components under the control of domain-general limited capacity controlled attention, it is controlled attention that is of primary importance for higher order cognition. Kane, Bleckley, Conway, and Engle (2001) further emphasize controlled attention as the ability to maintain a goal and inhibit irrelevant information that is responsible for individual differences in WM capacity in neurologically intact individuals. Cowan (1999) also posited similar WM processes as Baddeley's multi-component model but this model did not include domain-specific storage structures. In the Embedded Processes Model, two mechanisms, *attention-orienting system* and *central executive* compete for attention and determine representations that will enter conscious awareness. A smaller subset of items can fall under the *focus of attention*, allowing them to be maximally processed. Similar to Baddeley's multiple-component model, the Embedded Processes Model also assumes a limited duration and capacity. All of these models make similar assumptions about the relationship between STM and WM in that they are viewed as separate, but related processes.

For clarity purposes, here forward, verbal STM refers to limited capacity storage system for temporary storage of verbal information through subvocal rehearsal while placing minimal demands on domain-general executive processes. Similarly, spatial STM refers to limited capacity storage system for temporary storage of visuospatial information while placing minimal demands on central executive processing. Verbal and spatial WM include these respective storage systems, but add domain-general central executive processes such as updating, inhibiting irrelevant information, and shifting (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000).

2. Limitations of working memory tasks used with PWA

Working memory is of interest to aphasiologists because it has been hypothesized to underlie language processing problems in PWA and has been implicated as a contributor to language comprehension deficits in aphasia (Caspari et al., 1998; Sung et al., 2009; Tompkins, Bloise, Timko, & Baumgaertner, 1994). This assumption has resulted from findings of significant correlations between performance on verbal WM tasks and general language measures (e.g., Caspari, et al., 1998; Laures-Gore, Marshall, & Verner, 2011; Sung et al., 2009) making it difficult to determine the nature and direction of the relationship, or the cause of the relationship. For example, complex WM span tasks, such as reading and listening span, have been found to significantly correlate with performance on language tasks in both neurologically intact adults (e.g. Daneman & Carpenter, 1980) and PWA (e.g. Caspari et al., 1998; Tompkins et al., 1994), particularly for individuals with non-fluent aphasia (Ivanova et al., 2015; Ivanova, Kuptsova, & Dronkers, 2017). To perform complex span tasks, participants must comprehend sentences presented either orally or orthographically while also recalling a final word (either the last word in the sentence or a word presented after the sentence). The number of sentences and final words to be recalled is gradually increased. A person's WM span is determined by the total number of final words recalled. Though some researchers attribute correlational findings among listening or reading span and general language (comprehension and/or production) scores as evidence that WM impairments contribute to language impairments in PWA (e.g. Caspari et al., 1998; Tompkins et al., 1994), others have suggested an alternative explanation (Christensen & Wright, 2010; Martin, 1999; Wright & Fergadiotis, 2012). Martin (1999) asserted that the language deficit accounts for the lower WM scores on these complex span tasks for adults with aphasia. As the memory load increases on a complex span task (i.e., number of words to be recalled) the linguistic demands also increase (i.e., number of sentences to process). Martin (1999) suggested that participants, who are inefficient at processing sentences, require more time to process the sentences; and, in turn, have less time available to retain the sentence final words for recall. Similarly, Sung et al. (2009) suggested that WM and language share a single underlying construct. They completed a principle components analysis including verbal WM performance, reading comprehension, and language severity in a group of participants with different types of aphasia. They found that the WM and language measures loaded on a single factor which accounted for 76% of the variance in scores. This heavy verbal load in many WM tasks used with PWA may veil the true nature of WM deficits in aphasia.

One task that appears ideal for investigating WM in PWA is the *n*-back (Wright, Downey, Gravier, Love, & Shapiro, 2007). The *n*-back task enables investigators to manipulate linguistic load while also eliminating a requirement for verbal output (Christensen & Wright, 2010; Mayer & Murray, 2012; Wright et al., 2007). To complete an *n*-back, participants view stimuli one at a time on a computer screen. They press a button when the current item is identical to the one presented *n* back. It requires participants to decide whether each stimulus in a sequence matches the one that appeared *n* items ago; presumably requiring the individual to store and manipulate information, while also updating the contents in WM (Jonides, Lauber, Awh, Satoshi, & Koeppe, 1997). Successful performance requires temporarily storing and manipulating the temporal order of items. The temporal order of newly presented items must be updated while activation of previously relevant items is suppressed. The requirements of the task strongly parallel the definition of WM, indicating that the *n*-back has strong face validity. Construct validity has also been demonstrated (e.g. Schmiedek, Li, & Lindenberger, 2009; Shamosh et al., 2008; also cf.; DeDe, Ricca, Knilans, & Trubl, 2014). Further, the task is particularly ideal for investigating different WM processes.