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Measuring working memory deficits in aphasia

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ABSTRACT

Purpose: Many adults with aphasia demonstrate concomitant deficits in working memory (WM), but such deficits are difficult to quantify because of a lack of validated measures as well as the complex interdependence between language and WM. We examined the feasibility, reliability, and internal consistency of an *n*-back task for evaluating WM in aphasia, then explored the influence of domain-general (WM load, reaction time, age) and domain-specific (language) factors.
Method: Fourteen adults with aphasia and 12 age-and education-matched controls completed *n*-back tasks varying in stimulus type (high-frequency, low-frequency, or non-nameable stimuli) and WM load (0-, 1-, and 2-back). Data analyses explored the impact of these variables within and across participants and groups.
Results: *n*-Back scores were collectively reliable across conditions. Both groups performed similarly across stimulus types with significantly greater WM accuracy for nameable versus non-nameable stimuli. Compared to the controls, adults with aphasia were significantly more affected by increasing WM load. RT effects generally paralleled accuracy data, whereas age effects were inconsistent across tasks.
Conclusions: These data are consistent with WM deficits in aphasia, for which the *n*-back task holds promise for clinical quantification.

Learning outcomes: Readers will be able to: (a) define working memory, (b) discuss the difficulty inherent in removing language from a complex cognitive task, and (c) describe how the *n*-back task may contribute to measuring working memory capacity in individuals with aphasia.

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1. Introduction

Working memory (WM) refers to the ability to engage simultaneously in information processing and storage, in the service of some cognitive goal (Kane & Engle, 2002). The predominant model of WM (Baddeley, 1986, 2000; Baddeley & Hitch, 1974) follows from a hierarchical view of intellectual function, in which one area of the brain mediates predominately some general, superordinate ability (e.g., the *Supervisory Attentional System* (SAS, Glosser & Goodglass, 1990; Shallice, 1982), whereas other regions govern more specific subordinate abilities (Basso, De Renzi, Faglioni, Scotti, & Spinnler, 1973). That is, WM is thought to consist of domain-general, high-level cognitive control skills overlaid on domain-specific buffers. In contrast, the older concept of short-term memory consists solely of domain-specific buffers (e.g., Brown, 1958; Peterson & Peterson, 1959).

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Baddeley and Hitch's (1974) seminal paper on WM has motivated a large literature, and although their general definition of WM dominates many studies, a number of researchers have taken issue with the crystalized structure of their model (e.g., Postle, 2006). This has led to a fractionation of the WM literature, with many authors focused on the overlap between WM and the cognitive efficiency of the brain's domain-specific representational systems (Daneman & Carpenter, 1980, 1983; Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001; Just & Carpenter, 1992), and others stressing the centrality of domain-general, attentional control (Engle, 2002; Kane, Bleckly, Conway, & Engle, 2001). The concrete result of this fractionation is a wide variation in the methodology of WM studies, making a synthesis of this literature a complex undertaking.

Regardless of the lens through which WM is viewed, numerous studies have made clear the centrality of WM to both higher-level cognitive processing as well as to language processing. The intimate connections between WM and language have been demonstrated with respect to both behavioral and neurophysiological data (Alexander, 2006; Crosson et al., 1999; Murray, 2004), and across both healthy (Daneman & Carpenter, 1983; Just & Carpenter, 1992) and language-disordered populations (Baddeley, 1986; Gathercole, Pickering, Knight, & Stegmann, 2004). It follows that WM has been explored repeatedly in adults with aphasia. A large literature has established that individuals with aphasia demonstrate WM limitations affecting many aspects of linguistic and nonlinguistic processing (e.g., Caplan & Waters, 1999; Christensen & Wright, 2010; Friedmann & Gvion, 2003; Sung et al., 2009), and impacting functional communication as well as social, academic, rehabilitative, and vocational outcomes (Fillingham, Sage, & Lambon Ralph, 2005; Murray, 2004).

Despite the comprehensive nature of this literature base, the ability of clinicians working with adults with aphasia to rapidly, reliably assess WM and crucially, to meaningfully interpret and utilize the results of this assessment, is limited. There are likely several causative factors in play here. First, due to the fractionation of the WM literature itself, different aphasia laboratories have focused differentially on separate aspects of WM. For example, many aphasia researchers have examined short-term WM buffer capacity (e.g., Baddeley's "phonological loop") using tasks such as digit, word, non-word, and spatial span (Baldo & Dronkers, 2006; Beeson, Bayles, & Kaszniak, 1993; Friedmann & Gvion, 2003). Collectively, these studies have supported deficient articulatory rehearsal in patients with frontal lesions, and deficient phonological storage in those with more posterior (e.g., temporoparietal) lesions. Others have emphasized executive-type WM problems (e.g., Baldo & Dronkers, 1999; Gutbrod, Cohen, Mager, & Meier, 1989; Martin & Allen, 2008), identifying difficulties for adults with aphasia in processes such as inhibiting irrelevant information and updating the contents of WM (Miyake et al., 2000). Thus, a clinician wishing to assess WM in a patient with aphasia would have a very large number of very dissimilar tasks in the literature from which to choose. Secondly, few WM studies have specifically explored the validity, clinical feasibility, and reliability of WM tasks; those that have done so (e.g., Hockey & Geffen, 2004; Salthouse, Atkinson, & Berish, 2003; Waters & Caplan, 1996) have focused on healthy adults rather than clinical populations. Information regarding test–retest reliability and internal consistency is especially critical for individuals with aphasia, given their well-known variability in day-to-day linguistic and cognitive performance (Tseng, McNeil, & Milenkovic, 1993). Third, although it is known that the speed at which one can process information is linked to the amount of information one can retain (Daneman & Carpenter, 1980; Hockey & Geffen, 2004; Just & Carpenter, 1992; Kail & Salthouse, 1994; Miyake, Carpenter, & Just, 1994, 1995), and that processing speed is a major factor in age-related cognitive decline (Salthouse, 1996), this has been overlooked in a number of WM studies with adults with aphasia (e.g., Christensen & Wright, 2010; Tompkins, Bloise, Timko, & Baumgaertner, 1994). Finally, because many aphasia researchers have examined either specific, verbal WM limitations affecting semantic, phonologic, or syntactic processing (Caplan & Waters, 1999; Friedmann & Gvion, 2003; Martin & Ayala, 2004; Miyake et al., 1995), or the recall of strictly verbal information (Sung et al., 2009; Tompkins et al., 1994; Wright, Downey, Gravier, Love, & Shapiro, 2007), the resultant intertwining of language skills with WM capacity have made it difficult to separate out and interpret any proposed WM deficits.

In sum, despite the many published studies examining WM in adults with aphasia, there is a need for research to examine the clinical feasibility and reliability of WM tasks as well as the influence of domain-general (e.g., reaction time, age), and domain-specific (e.g., language ability) factors to aid in interpreting assessment results and sorting out the roles of domain-specific versus -general factors in generating intra-individual WM differences (e.g., Engle, 2002). Therefore, the purpose of the present study is to examine one version of the *n*-back task for measuring WM, including its basic psychometric properties as well as its utility for providing insight into the nature of WM deficits in aphasia. The following brief literature review will serve to: (1) summarize how WM has been measured previously in adults with aphasia and (2) establish the rationale for examining an *n*-back task with a sample of this population.

1.1. Measuring working memory capacity in aphasia

The most commonly used task to tap WM capacity in non-brain-damaged adults has been the complex span task (CST). Most CSTs follow the design of Daneman and Carpenter's (1980) original reading span, which required reading aloud sets of sentences and, at the end of a set, recalling the last word of each sentence; in this task, WM capacity is operationally defined as the number of sentence-final words recalled. For individuals with aphasia, researchers have simplified the reading span task (Caspari, Parkinson, LaPointe, & Katz, 1998), changed task input and response modalities, or both (Friedmann & Gvion, 2003; Tompkins et al., 1994). For example, Tompkins et al. (1994) used a modified auditory span task to identify WM deficits in adults with left-hemisphere and right-hemisphere brain damage compared to healthy controls; additionally,

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