Introduction

Non-linguistic cognitive deficits are commonly associated with linguistic deficits in aphasia (Helm-Estabrooks, 2002; McNeil, Odell, & Tseng, 1991). Deficits in working memory (WM) are a critical subset of such non-linguistic deficits (Murray, Ramage, & Hooper, 2001; Wright & Shisler, 2005). Tompkins, Bloise, Timko, and Baumgaertner (1994) initially demonstrated that participants with left hemisphere injuries made more errors on a WM task than control participants without neurological impairment. Those findings were substantiated by Caspari, Parkinson, LaPointe, and Katz (1998), demonstrating an association between WM capacity and general language abilities in people with aphasia. Friedmann and Givon (2003), Wright, Newhoff, Downey, and Austermann (2003), and Wright, Downey, Gravier, Lover, and Shapiro (2007) have further supported the relationship between WM and linguistic comprehension. 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 experimental confounds. The aims of this paper are to examine potential confounds in studies of WM in aphasia and provide a framework for developing alternative methods to reduce such confounds.

Limitations of existing WM measures

Complex Span Tasks

Assessment of WM in people with and without aphasia often includes modifications of Daneman and Carpenter's (1980) complex span tasks. In a typical complex span task, a processing task (e.g., sentence reading, arithmetic problem-solving), is given along with a set of stimuli (e.g., letters, words) to be remembered for later recall. Most complex verbal span tasks involve linguistic (reading and/or spoken) stimuli. Potential confounds, especially when applied to people with aphasia, include linguistic abilities implicated in the processing component, and language, speech and motor abilities required for responding. Modifications have included 1) grammatical simplification and shortening of linguistic stimuli so that people with aphasia may achieve desired levels of accuracy (Caspari et al., 1998; Tompkins et al., 1994), and 2) changing of the response task to one of recognition rather than recall of to-be-remembered items to reduce confounds of linguistic expression (Caspari et al., 1998). Such modifications hold promise, although the reliability and validity of methods incorporating these modifications have not yet been established. Further complicating the utility of such modifications is the inconsistency of modifications across studies, making the comparison or aggregation of findings problematic.

Moreover, the validity of comparisons between the participants with and without aphasia on the modified complex span tasks has not been established. Simplification and/or shortening of the processing component for participants with aphasia may cause the intended WM index to actually index short-term storage in participants with milder forms of aphasia and those without aphasia (Turner & Engle, 1989).

Further complicating the study of WM is the inconsistency of scoring methods used across studies. Scoring generally includes a span score (largest set size recalled correctly) or an item score (total number of items recalled correctly). Wright et al. (2003) created composite scores incorporating a combination of accuracy on true/false judgments and number of items recalled. The shortcoming of this method is that an identical score for two participants may reflect different patterns of performance and details about the nature of the relationship between WM and language comprehension are obscured.

Another inherent confound in studies of the association between WM and linguistic ability in aphasia is the use of linguistic stimuli in modified span tasks as well as in the tasks used to assess language impairment. Use of linguistic tasks across comparative measures leads to common variance for both measures (Wright & Shisler, 2005), and consequently any significant correlations are suspect. To illustrate, the first author of this paper analyzed patient data reported by Caspari et al. (1998). Listening and reading span scores were strongly correlated with scores on the Western Aphasia Battery (Kertesz, 1982) and the Reading Comprehension Battery for Aphasia (LaPointe & Horner, 1979). However, when controlling for severity of impairment, the magnitude of correlations decreased; only the partial correlations between listening (not reading) span and overall scores on the two aphasia tests remained significant. Clearer conclusions about the nature of the relationship between WM and language abilities in people with aphasia require careful control for the type and degree of preserved linguistic abilities. Replacing verbal with nonverbal stimuli would also minimize confounds between WM and linguistic performance indices, permitting clearer conclusions about the nature of any overlap between measures of the two constructs.

N-Back Tasks

N-back tasks have also been used to measure WM capacity in participants with and without aphasia (Friedmann & Givon, 2003; Wright et al., 2007) In N-back tasks, participants are instructed to judge whether an auditory or visual stimulus matches a previous stimulus presented n items before. N-back task measures lead to inherent confounds in that it is not possible to ensure that only WM, and no other aspect of memory, is indexed. Supporting this notion, Kane, Conway, Miura, and Colflesh (2007) compared N-back task performance with operation span scores for adults without cognitive or linguistic impairment and found no significant correlations.

Backward Span Tasks

In backward span tasks, participants are instructed to recall a list of spoken items in reverse order. Backward span measures have inherent confounds in the study of WM because processing is performed on the same items to be stored, such that it is not possible to rule out that something other than WM is being measured. This confound may underlie the inconsistency in experimental findings between Engle, Tuholski, Laughlin, and Conway (1999), who reported that backward digit span scores did not load onto the same factor as complex span scores, and Waters and Caplan (2003), who reported that they did.

Proactive Considerations for Future Research

Based on potential confounds in WM tasks and measures, it is important to delineate critical aspects of methodological control for use in future studies, especially those including participants with language disorders. Important areas for control are:

1. Dependence on comprehension of complex task instructions;
2. Degree of linguistic processing demand in WM and language tasks;
3. Degree of specific linguistic deficits in participants;
4. Difficulty of processing components in light of each participant's linguistic abilities;
5. Separation of processing and storage components of WM tasks;
6. Distinction of WM processing scores from WM storage scores;

7. Response requirements;
8. Reliability and validity of new or modified tasks or measures based on people with and without aphasia; and
9. Standardization of procedures and scoring methods.

Based on these suggested areas of control, the following possibilities may hold promise.

1. Modify the simplified version of the Daneman and Carpenter (1980) reading/listening span task (Tompkins et al.,1994; Caspari et al., 1998)) by: a) incorporating verbal span tasks that are distinct from other linguistic processing tasks, b) controlling for participants' linguistic abilities, c) establishing reliability and validity for persons without neurological impairment, d) permitting a nonverbal response, and e) controlling for potential motor response confounds.
2. Use spatial, operation and counting span tasks to reduce linguistic processing confounds and distinguish WM from language measures.
3. Incorporate eye tacking methods to reduce reliance on comprehension of task instructions, allow for nonlinguistic responses, and yield online processing measures.

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