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INTRODUCTION

Short-term/working memory impairments in aphasia: Data, models, and their application to aphasia rehabilitation

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Much of the extant research in language processing and language impairment has focused on elements of linguistic representation that are accessed and retrieved in comprehension, repetition, and production of words and sentences. These studies have provided important information about the effects of characteristics of words (e.g., frequency, imageability) and sentences (e.g., syntactic and semantic argument structure) on language processing. A smaller but nonetheless rapidly growing body of research has been directed to understanding those cognitive processes that mediate access, maintenance, and retrieval of those representations. This line of investigation has increased dramatically in the last two decades. One impetus for this increased interest in the relations of language and other cognitive processes is intuitive: language function involves content *and* process. Language representations comprise the content, but the abilities that support access, maintenance and retrieval of these representations are not specifically linguistic in nature. Rather, they reflect the mechanics of language processing that act as the essential "supporting cast" or substrate upon which many other linguistic functions rely (e.g., working memory supports both naming and complex syntactic tranformations). A second impetus is motivated by clinical and empirical considerations: individuals with aphasia frequently present with co-morbid impairments of extra-linguistic cognitive processes such as verbal STM (Martin & Ayala, 2004; R. Martin, Shelton & Yaffee, 1994) and executive functioning (Murray & Ramage, 2000).

The two language support systems addressed in this special issue of *Aphasiology* are short-term memory (STM) and working memory (WM). These are overlapping abilities in two ways. STM refers to a person's capacity to maintain activation of language representations and is typically measured by span tasks such as serial immediate

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recall of linguistic items such as digits, words, and nonwords. It is often viewed as a temporary, passive store of detail relative to its more active brother WM, which maintains and manipulates information in the short term in support of problem solving and task completion. STM capacity is an integral component of WM, and therein lies the overlap of the two systems, but WM is further supported by executive processes that do the "work", so to speak. It has been proposed that some executive processes involved in the functions of verbal WM include inhibition, working memory updating, and set shifting (Miyake et al., 2000) and attention (Astle & Scerif, 2009; Posner & Petersen, 1990). These capacities help to control and work with language representations in WM as they are considered and compared to other information in WM or long-term knowledge. For example, most complex problem-solving tasks require WM in that virtually all require: (1) time and means to keep some information inhibited while attention is directed to other information, (2) a means to switch back to the temporarily suppressed information, and (3) a means to keep track of what has been considered and updated in some way.

The papers in this issue focus on theoretical accounts of the role of STM and WM in language processing as well as clinical applications that reflect a focus on these mechanisms of cognitive support to language processing. Each paper provides a theoretical perspective on or clinical application of the most current empirical evidence regarding the role of cognitive processes in relation to language processing. Also common to each paper is an acknowledgement of the need for additional theoretical and clinical research in this area. Although in its relative infancy, research addressing relations between language and other cognitive processes is integral for advancing our understanding of the dynamic nature of language impairment in aphasia and also for directly informing its treatment.

The special issue begins with three review papers. The first (Wright & Fergadotis) is a review of several models of WM that have been used to frame our understanding of WM disorders in individuals with aphasia (as well as populations without language impairment). The authors also provide reviews of (1) tasks used to measure WM and (2) empirical studies of WM in relation to language processing in aphasia. This overview is followed by a second review paper (Caplan, Waters, & Howard), which provides an in-depth review of the highly influential working memory model proposed Baddeley and Hitch (1974). The authors critically evaluate this model's ability to account for neuropsychological cases that involve impairment of verbal STM/WM. Additionally they provide a critical review of more recent accounts of verbal STM/WM impairments and language processing in aphasia. The third review paper (Murray) focuses on treatment and evaluates recent studies that focus on direct or indirect approaches to remediation of STM and WM deficits. Although only a small number of such treatment studies have been reported, the initial results are promising, and Murray emphasises the need for more research in this area to establish the reliability and validity of the current and future studies that assume a role of STM/WM in language processing and acquired language impairment.

Following these three review papers there are a series of empirical papers that aim to improve our understanding of the cognitive and neural components of STM and WM. The first is a study of the neural correlates of verbal STM and repetition (Baldo, Katseff, & Dronkers). The arcuate fasciculus has long been associated with repetition disorders (e.g., Bernal & Ardila, 2009; Geschwind, 1972) as classically associated with conduction aphasia. Much controversy persists as to the role of this specific tract in supporting word repetition. Baldo et al.'s lesion mapping analyses indicate a common

area supporting both AVSTM and repetition in the left posterior temporo-parietal cortex. These findings shed light on the debate of the role(s) of the arcuate fasciculus within the cortical language network. Baldo and colleagues have also offered a unique integrative perspective that can account for many repetition/STM disorders in syndromes beyond conduction aphasia.

Studies that focus on the association of two abilities, repetition and AVSTM, provide one window on the relationship of language and STM and how they are associated. Another approach is to determine whether these two cognitive domains can be dissociated. This was the approach advanced by Attout, Van der Kaa, George, and Majerus, who provide such evidence in the study of retention of item vs order information in immediate serial recall, the former being linked with language processing and the latter with STM processing. They report two case studies with contrasting patterns of performance on a series of STM and recall tasks that focused on retention of either item or order information. Whereas one case with a mild phonological impairment showed poor item recall and good order recall, the other case with no residual language impairment showed the opposite pattern. Their study makes clear the importance and the challenge in teasing out verbal and STM components in a verbal STM task.

Hoffman, Jefferies, Ehsan Jones, and Lambon Ralph use a different approach to provide evidence for a dissociation of language and STM components of verbal STM. They contrast differences in performance of individuals with transcortical sensory aphasia (TSA) and those with semantic dementia (SD). In keeping with the idea that TSA impairs access to intact semantic information and SD reflects a degradation of semantic knowledge, they found that semantic and syntactic coherence influenced repetition/recall of word lists by individuals with TSA, but not individuals with SD.

Reilly, Troche, Paris, Park, Kalinyak-Fliszar, Antonucci, and Martin examined the nature of lexicality errors in recall of word and nonword sequences in types of impairment, progressive nonfluent aphasia (PNA), and semantic dementia (SD). The former is associated with phonological impairment and the latter with semantic impairment. Their analyses indicate that errors in each group reflect a reliance on the relatively preserved language domain (semantic in PNFA and phonological in SD). These results have clinical relevance, as they are consistent with the view that characteristics of the output of a repetition task in individuals with language impairment reflect access to preserved levels of processing.

The study conducted by Allen, R. Martin, and N. Martin involves an investigation of semantic and phonological STM abilities in aphasia in relation to executive processing abilities. Although research by Hamilton and R. Martin (2005) and Hoffman, Jefferies, Ehsan, Hopper, and Lambon Ralph (2009) indicated that semantic STM and processing are related to some or all executive abilities, this relationship was not confirmed in Allen et al.'s extensive series of regression analyses involving executive functions and semantic and phonological STM capacities, as well as semantic processing. Their results are discussed in relation to a recently proposed account of semantic STM deficits by Barde, Schwartz, Chrysikou, and Thompson-Schill (2010) that attributes semantic and phonological STM deficits to a consequence of overly rapid decay of information.

N. Martin, Kohen, Kalinyak-Fliszar, Soveri, and Laine investigated the role of semantic and phonological processing abilities, semantic and phonological STM capacities, and executive functions on sensitivity to an increase of working memory load in tasks requiring judgements of semantic and phonological similarity of words.

They found that, for those participants with aphasia, accuracy of performance on these tasks decreased significantly when verbal WM load inherent in the judgement task was increased. Regression analyses revealed that semantic STM and the executive function of inhibition were the strongest predictors of a working memory load effect on performance. Additionally, the effects of these two variables were not correlated with each other. Martin et al. discuss the theoretical and clinical implications of these data.

Gvion and Friedmann investigated the effect of phonological WM impairment on sentence comprehension. These authors found that phonological WM is not involved when sentence comprehension requires semantic-syntactic reactivation of information. In contrast, phonological WM capacity is strongly related to sentence comprehension when phonological reactivation is required over a long distance in a sentence. The data reinforce earlier findings that sentence comprehension in conduction aphasia is intact under most, but not all, circumstances. The theoretical and clinical relevance of these findings are discussed.

The third section of this special issue of *Aphasiology* includes three papers that focus on measurements of verbal STM and WM in aphasia. The first two papers investigate the use of eye tracking to measure STM/WM. Papagno, Bricolo, Mussi, Daini, and Cecchetto present a longitudinal case study to determine whether eye movement monitoring is sensitive to processing of relative clause sentences, and whether that sensitivity is further affected by impaired STM compared to controls. Results confirmed this hypothesis. The authors discuss the theoretical and clinical relevance of this study. Ivanova and Hallowell's study investigates the validity of a WM task involving eye movement measurements. The authors report four findings of clinical or theoretical interest. First, concurrent validity of the eye movement WM task and another measure of WM was established. Second, the eye movement WM task effectively discriminated between performances of participants with and without aphasia. Third, in contrast to their predictions and other findings in the literature, the WM scores from this task did not correlate with a comprehensive assessment of language in aphasia (the Western Aphasia Battery; Kertesz, 2007). Finally, the eye-tracking measures did not indicate any trade-off between processing and storage as working memory load increased, suggesting that such an increase did not require allocation of more resources to the task. Implications of these findings and need for further research are discussed.

In the final paper of this issue, Gvion and Friedmann present a test battery designed to assess phonological processing and STM abilities in aphasia. This study includes data from individuals with conduction aphasia, and a group of healthy adults spanning six age groups. The battery is in Hebrew and includes 10 recall and recognition span tests that are designed to measure effects of variables such as frequency and lexicality on performance. It should serve as a comprehensive model to develop similar batteries in other languages.

At the beginning of this Introduction we noted that the papers in this issue share common ground in that they are describing or offering theories and research that are relatively new and, in that sense, groundbreaking. It is a goal of this special issue to inspire further research on the relation of language and other cognitive processes such as STM and WM and to promote applications of the theoretical ideas and empirical outcomes to the diagnosis and treatment of language disorders. This will require an expansion of our view of aphasic impairment to include processing aspects of language function in conjunction with the content of language. The papers in this special issue reflect an evolution in the level of description of aphasic impairment from

neuroanatomical taxonomies and cognitive models of linguistic components of language processing to current connectionist models that emphasise the processes that enable access and retrieval of the language representations.

We can look forward to an exciting and challenging time in aphasia research as these new approaches to understanding the nature of aphasia guide our conception and implementation of empirical and clinical research. As editors we are indebted to our world-class contributors and thank them for the time, effort, and knowledge put into studies and reviews that make up this special issue. We must also extend great thanks for the wisdom, patience, and oversight of Chris Code. Without his support this work would not have come to fruition.

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