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Effects of working memory demands on sentence production in aphasia

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ABSTRACT

The purpose of the study was to investigate the effects of task demands on sentence production and their relation to working memory (WM) capacity in people with aphasia using a verb-final language. The current study manipulated the WM loads on the sentence production tasks by varying the following three factors: task type (syntactic priming vs. sentence completion), sentence type (active vs. passive), and canonicity (canonical vs. noncanonical word order). Task type and word order canonicity were related to individual differences in WM capacity in both people with aphasia and their normal controls.

1. Introduction

Researchers have reported that several cognitive and linguistic factors affect sentence production in aphasia (e.g., [Baddeley & Hitch, 1974](#); [Just & Carpenter, 1992](#)). Sentence production is a complex process involving several stages, including conceptualization, syntactic construction, and phonological selection. To successfully produce a complete sentence, speakers need to activate multiple stages by simultaneously coordinating semantic, syntactic, and phonological selections ([Garrett, 1976, 1982, 2000](#); [Levelt, Roelofs, & Meyer, 1999](#); [Martin, Yan, & Schnur, 2014](#); [Vigliocco & Hartsuiker, 2002](#)). This process requires cognitive resources, and one can assume that greater cognitive resources need to be engaged as the syntactic complexity increases.

Effects of syntactic complexity have been reported primarily focusing on the domains of sentence comprehension ([Gordon, Hendrick, & Johnson, 2001, 2004](#); [Demberg & Keller, 2008](#); [Gibson, 1998, 2000](#); [Grodner & Gibson, 2005](#); [King & Just, 1991](#); [Lewis & Vasishth, 2005](#); [Lewis, Vasishth, & Van Dyke, 2006](#); [McElree, Foraker, & Dyer, 2003](#); [Wanner & Maratsos, 1978](#)). Syntactic complexity has been manipulated in several ways. A group of researchers argued that passive sentences are more complex to process than sentences with active structures due to the movement process of the noun phrases (e.g., [Grodzinsky, Pinango, Zurif, & Drai, 1999](#)). Grodzinsky and colleagues suggested that people with aphasia demonstrated chance-level performance on passive sentence comprehension tasks. They accounted for the findings based on the specific impairment hypothesis, which posits that the coindexation process can be impaired or lost by deleting the traces of the structures moved from their original places ([Obler, Nicholas, Albert, & Woodward, 1985](#); [Obler, Fein, Nicholas, & Albert, 1991](#); [Rochon, Waters, & Caplan, 1994](#); [Waters, Rochon, & Caplan 1998](#)).

Another group of researchers accounted for the syntactic complexity effects from the perspective of processing resources. [Caplan, Waters, DeDe, Michaud, and Reddy \(2007\)](#) referred to processing resources as cognitive architecture that serves cognitive operations to perform mental computations. Processing resources in sentence comprehension domains were refined by the concept of working memory (WM) capacity. The notion of Working Memory (WM) was first introduced by [Baddeley and Hitch \(1974\)](#), proposing a system comprising multiple components. A three-component system consists of a central executive and its two slave subsystems: the

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phonological loop concerned with acoustic and verbal information and the visuospatial sketchpad involved in visual and spatial information (Baddeley, 1986). Some researchers developed the notion of the central executive in Baddeley's WM model by applying "capacity" or "resource" concepts to language processing.

Just and Carpenter (1992) defined WM capacity as the maximum mental resources available to be engaged in maintaining and processing linguistic computations. Researchers found that people with higher WM capacity demonstrated higher accuracy and lower reaction time than individuals with lower WM capacity in sentence processing, especially when the syntactic structure became more complex. Carpenter, Miyake, and Just (1994) suggested that the overall performance on sentence comprehension decreased as syntactic complexity increased or as the number of syntactic complexity factors increased regardless of task type (e.g., object-manipulation task in Caplan, Baker, & Dehaut, 1985; Caplan & Hildebrandt, 1988; sentence-picture matching task in Naeser et al., 1987). These results are consistent with the resource reduction hypothesis, in that performance degradation manifests itself only when the task demands are high enough to tax the resources available in people with aphasia.

Another group of WM researchers focused on the attentional components of WM, suggesting that WM is regarded as the executive attention. However, this group of researchers brought up slightly different aspects of WM, such as cognitive attention and resources, from Just and Carpenter's WM model (1992) by focusing on the notion of inhibition and interference effects (Connelly, Hasher, & Zacks, 1991; Hasher & Zacks, 1988; Kane & Engle, 2002; Zacks & Hasher, 1993). They suggested that individual differences in WM capacity are associated with the ability to inhibit irrelevant information to maintain the goal of the task in the face of interference. Interference- and inhibition-based WM models were applied to sentence-processing domains mostly focusing on similarity-based interference effects (e.g., Gordon, Hendrick, & Levine, 2002). Evidence suggested that readers encountered significantly greater interference when the noun properties were similar among the noun phrases that needed to be processed in a sentence. However, very few studies have examined the effects of WM demands on sentence-production domains, especially for people with aphasia by manipulating the linguistic components under the theoretically motivated WM framework. The current study manipulated several linguistic components by varying the syntactic structures, word-order canonicity, and task paradigm to increase WM demands in sentence production for people with aphasia. The theoretical motivations for employing each component of the linguistic manipulations were further elaborated as below by reviewing each component of the linguistic manipulations for syntactic structure, elicitation task paradigm, and word-order canonicity.

Sentence production is a complex process involving activating, planning, and integrating multiple levels of linguistic units, and the process requires WM resources (Martin et al., 2014). Certain types of sentences require greater WM resources than other sentences. For example, Gibson and colleagues suggested that syntactic structures that contained linguistic units to be integrated over a longer distance required greater WM resources than sentences with local dependency (Gibson, 1998; Hawkins, 1994, 2004; Scontras, Badecker, Shank, Lim, & Fedorenko, 2015). However, the results of sentence production studies need to be interpreted with caution, given that the results may be affected by the type of elicitation task used.

Studies that employed a picture description paradigm reported that participants prefer to use simpler structures (e.g., Gennari, Mirkovic, & MacDonald, 2012; Temperley, 2007). However, based on the evidence from connected speech samples, it is hard to determine whether participants produce simpler structures because the complex sentences demand more resources or simply because they rarely need to produce complex structures in conventional language production environments. Some previous studies in the aging literature examined sentence production performance as a function of linguistic complexity and cognitive demands using a constrained sentence production paradigm (Kemper, 1986; Sung, 2015). They found that elderly adults did not differ from younger populations in terms of the levels of syntactic complexity produced in connected speech samples. In contrast to the studies using a constrained sentence production paradigm, researchers consistently found that elderly adults demonstrated greater difficulties in producing complex sentences as a function of the cognitive resources required to formulate the syntactic structures (Baddeley & Hitch, 1974; Just & Carpenter, 1992; Morris, Gick, & Craik, 1988; Perfect & Maylor, 2000; Sung, 2015; Waters & Caplan, 2001).

Sung (2015) employed two sentence production paradigms to elicit different levels of syntactic complexity by varying the cognitive demands of the task. One was based on the syntactic priming paradigm, and the other was based on the sentence completion task. In the priming paradigm, speakers needed to hold the primed syntactic structure in their WM buffer so that they could utilize the same syntactic structures to produce the target sentence. In contrast, for the sentence-completion task, speakers were given the initial noun phrase to produce along with the semantic units for each linguistic component (e.g., verbs, agents, and themes) in a written format. For several reasons, it was assumed that the priming paradigm requires greater recruitment of WM resources than the completion task. First, the priming paradigm requires the memory buffer to keep the prime sentences activated while reversing the thematic roles of the noun phrases for the target sentence. This process involved in the priming task may be related to the ability to maintain and simultaneously compute the linguistic units from WM resources, as suggested by Just and Carpenter (1992)'s model of WM. Another possible explanation from the interference-based WM models relates to the alternative underlying cognitive mechanisms engaged in the priming paradigm. In the priming paradigm, two sets of pictures were presented with one for the prime and the other for the target, in which the thematic roles were reversed between the prime and target pictures. The visual similarity of the two pictures may elicit similarity-based interference effects at the visual-processing level. In the verbal-output domain, speakers need to inhibit the automatic activation of the prime sentences by not repeating what has just been told in order to reach the goal of reversing the thematic roles using the primed syntactic structures. In this regard, the interference- and inhibition-based WM models seem to account for the relatively greater WM demands imposed on the priming paradigm compared to the completion measure. Another critical component that increases the WM demands in the current sentence production study is the manipulation of the syntactic complexity by varying the syntactic structure (active and passive) and the canonicity of word order in the verb-final language, Korean. Active and passive sentence comparisons have been reported in several studies for English-speaking individuals with aphasia (Obler et al., 1985, 1991; Rochon et al., 1994; Waters et al., 1998) by replicating the results that passive sentences are

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