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# Deficit-lesion correlations in syntactic comprehension in aphasia

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ABSTRACT

The effects of lesions on syntactic comprehension were studied in thirty-one people with aphasia (PWA). Participants were tested for the ability to parse and interpret four types of syntactic structures and elements – passives, object extracted relative clauses, reflexives and pronouns – in three tasks – object manipulation, sentence picture matching with full sentence presentation and sentence picture matching with self-paced listening presentation. Accuracy, end-of-sentence RT and self-paced listening times for each word were measured. MR scans were obtained and analyzed for total lesion volume and for lesion size in 48 cortical areas. Lesion size in several areas of the left hemisphere was related to accuracy in particular sentence types in particular tasks and to self-paced listening times for critical words in particular sentence types. The results support a model of brain organization that includes areas that are specialized for the combination of particular syntactic and interpretive operations and the use of the meanings produced by those operations to accomplish task-related operations.



## 1. Introduction

This paper presents new data regarding deficit-lesion correlations in the area of syntactic comprehension in PWA. We begin with a brief introduction to syntactic comprehension, then review work relating lesions to disorders of syntactic comprehension, and then present our study.

The term "syntactic comprehension" refers to the processes of assigning syntactic structure to linguistic input (often called "parsing") and using that structure to determine propositional meanings (sometimes called "interpretation"). Syntactic comprehension is an important human cognitive function because propositional meanings express relations between concepts that are not inherent in word meanings themselves, such as who is accomplishing and receiving an action (thematic roles of agent, theme, etc.), how mental states are related to one another (what a person believes, desires, intends, etc.), and others, which are critical to the power of language to represent the world and to aid in thinking and communicating. The propositional meaning of a sentence is determined by its syntactic structure, not simply by associating words to one another, allowing sentences to express unlikely or even impossible relations between items. For example, sentences such as "The man bit a dog" or "A dog was bitten by the man" mean that a particular man bit a dog, not the more likely event that a dog bit the man, because the syntactic structure of these sentences forces this interpretation. The ability to represent unlikely events allows humans to express ideas about what might happen under various possible circumstances; that is, to express counterfactual statements. This ability is critical for inter-individual communication that is used in planning of actions, scientific work, instruction, social organization, and other human activities that involve more than one person.

Although there is considerable disagreement about many details of syntactic structures and how they are constructed from auditory input, there is also widespread agreement about basic features of these representations and their processing. Virtually all contemporary linguistic theories maintain that syntactic representations are complex sets of syntactic categories (noun, verb, verb phrase, etc.) that are hierarchically organized, and that different structures – or different relations among categories in these hierarchical structures – determine different aspects of propositional meaning (thematic roles, the antecedents of pronouns and reflexives, etc.) (Chomsky, 1995; Culicover & Jackendoff, 2005). Virtually all models also agree that, although some aspects of syntactic representations – such as their hierarchical structure – are found in other domains such as mathematics, music and even action organization, and in some animal functions, the specific combination of nodes, organization, and semantic interpretation found in syntax is a unique biological entity (Caplan & Gould, 2008). Virtually all models of speech comprehension maintain that syntactic structures are built and interpreted incrementally (as each word is encountered) (Hale, 2001; Levy, 2008; Lewis & Vasishth, 2005).

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On-line behavioral measures of syntactic comprehension reflect the operation of parser/interpreter more directly than end-of-sentence measures, which are affected by memory for the content of a sentence, response selection, and other cognitive operations.

The areas of the brain that are involved in syntactic comprehension are of interest for many reasons. Clinically, knowing what brain areas support this function would be expected to help predict the effects of lesions. Scientifically, understanding the neural basis for syntactic comprehension would provide information about the way the human brain is organized to support a unique, and uniquely human, function. This could be a model for other human cognitive functions, or provide evidence that different human cognitive functions are supported in different ways by the brain.

The effects of lesions on syntactic comprehension provide information about the areas of the brain that are necessary for this function. The "deficit-lesion correlation" approach requires both an analysis of the deficits in normal functions that, along with compensatory mechanisms, produce the observed abnormal behaviors and an analysis of the brain areas that are lesioned. Lesions can be described in many ways (e.g., as areas of infarction, areas of hypoperfusion, areas of hypometabolism, patterns of disconnection, etc.); the focus of most work has been on areas of infraction and the implications of their associated deficits for functional specialization of areas of the brain ("localization of function"). We briefly review the criteria for demonstrating that a person with aphasia has a deficit in syntactic comprehension and methods for establishing the location and size of a lesion.

Criteria for diagnosing a syntactic comprehension emerged from the first paper on this subject, by Caramazza and Zurif (1976). These authors described PWA who could not match syntactically complex, semantically reversible ("experimental") sentences (1) to a picture but could match syntactically simple, semantically reversible ("baseline") sentences (2) and semantically constrained sentences (3) to pictures (the term "semantically reversible" indicates that any person or item in the sentence could either perform or receive the action depicted by the verb in the sentence).

1. Syntactically complex, semantically reversible sentence
   The boy who the girl chased was tall
2. Syntactically simple, semantically reversible sentence
   The boy chased the tall girl
3. Semantically irreversible sentence
   The apple the boy was eating was red

Caramazza and Zurif (1976) explained the selectivity of the abnormal comprehension performance in the following way. The good performance on semantically constrained (or "irreversible") sentences (3) indicated that their PWA were able to understand words and to combine the concepts that words evoked into propositions. The good performance on syntactically simple, semantically reversible sentences (2) further indicated that they could apply simple "heuristics," such as assigning the nouns in a sentence the thematic roles of agent and theme on the basis of their order of occurrence. The poor performance on syntactically complex, semantically reversible sentences (1) indicated that they could not assign the thematic roles in a sentence by applying syntactic rules to sequences of words.

Since 1976, the criteria for diagnosing a syntactic comprehension deficit have been refined, although the essentials of the criteria have remained the same. The intent and effect of the refinements have been to increase the likelihood that a person with aphasia who has an observed pattern of behavior has a deficit in syntactic comprehension and not in a related functional ability.

One widely adopted practice is to match the baseline and experimental sentences more closely. Thus, for instance, rather than use (2) as the baseline for (1), a baseline such as (4) might be used:

4. Syntactically simple, matched, semantically reversible sentence
   The boy who chased the girl was tall

(4) is semantically reversible and can be understood by using a heuristic based on the order of the nouns in the sentence (the sentence-initial NP is the agent of every verb), and so qualifies as a baseline sentence. The fact that (4) is matched to (1) in terms of words, length, and number of thematic roles allows for the conclusion that selectively poor performance on (1) is due to an inability to apply the parsing and interpretive operations found in (1) and not in (4) more clearly than a difference in performance between (1) and (2) does.

A second change in approach has been to study syntactic comprehension in PWA using on-line measures rather than end-of-sentence accuracy. As noted, end-of-sentence performance involves memory for sentence meaning (and possibly form) and is distant from the incremental processing of syntactic structure. Studies using word monitoring (Tyler, 1985; Tyler, Ostrin, Cooke, & Moss, 1995), on-line anomaly detection (Shankweiler, Crain, Gorell, & Tuller, 1989), cross modal priming (Balogh, Zurif, Prather, Swinney, & Finkel, 1998; Burkhardt, Piñango, & Wong, 2003; Love, Swinney, Walenski, & Zurif, 2008; Love, Swinney, & Zurif, 2001), self-paced listening (Caplan & Waters, 2003; Caplan, Waters, DeDe, Michaud, & Reddy, 2007) and eye tracking in sentence picture matching (Hanne, Sekerina, Vasishth, Burchert, & De Bleser, 2011; Meyer, Mack, & Thompson, 2012) and in the visual world paradigm (Dickey, Choy, & Thompson, 2007; Dickey & Thompson, 2009; Thompson & Choy, 2009) have provided empirical data relevant to mechanisms that might underlie these disorders. Hypotheses regarding the mechanisms that produce syntactic comprehension disorders that have emerged from on-line studies include the ideas that the deficit consists of slowed lexical processing (Balogh et al., 1998; Love et al., 2001, 2008), slowed processing of syntactic structure (Burkhardt et al., 2003), slowed integration of lexical and syntactic information (Meyer et al., 2012), and excessive sensitivity to meanings derived from sources other than parsing and interpretation (Caplan, 2015).

A third change, not widely adopted, is to gather information on the performance of PWA in more than one task. Caplan, DeDe, and Michaud (2006), Caplan, Waters, DeDe, Michaud, et al. (2007) and Caplan, Michaud, and Hufford (2013a) showed that performance in individual PWA differed for the same sentence type in different tasks, indicating that a performance in one task is not a reliable measure of parsing and interpretation. Caplan et al. (2006, 2013a) and Caplan, Waters, DeDe, Michaud, et al. (2007) argued that abnormalities in syntactic comprehension that are seen only in one task are deficits in the ability to combine parsing and interpretation with the operations needed to perform a task, not deficits in parsing and interpretation themselves. Deficits in parsing and interpretation themselves should be task-independent.

On the neurological side, delineation of lesions on CT and MR scans is now standard in lesion-deficit correlation studies of syntactic comprehension deficits. The methods used to determine the location and size of lesions vary across studies and all face challenges in identifying some lesion boundaries (e.g., boundaries of lesions that abut the subarachnoid space or the ventricle). A few studies have included imaging of perfusion and metabolism, which usually identify larger areas of lesion than seen on CT or "structural" MR scans, and of white matter connectivity.