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Neural correlates of lexicon and grammar: Evidence from the production, reading, and judgment of inflection in aphasia

Michael T. Ullman[a,*], Roumyana Pancheva[a,b,c], Tracy Love[d], Eiling Yee[a,e], David Swinney[d], Gregory Hickok[f]

[a] *Brain and Language Lab, Department of Neuroscience, Georgetown University, USA*
[b] *Department of Linguistics, University of Southern California, USA*
[c] *Department of Slavic Languages and Literatures, University of Southern California, USA*
[d] *Department of Psychology, University of California, San Diego, USA*
[e] *Department of Cognitive and Linguistic Sciences, Brown University, USA*
[f] *Department of Cognitive Sciences, University of California, Irvine, USA*

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Abstract

Are the linguistic forms that are memorized in the mental lexicon and those that are specified by the rules of grammar subserved by distinct neurocognitive systems or by a single computational system with relatively broad anatomic distribution? On a dual-system view, the productive *–ed*-suffixation of English regular past tense forms (e.g., *look–looked*) depends upon the mental grammar, whereas irregular forms (e.g., *dig–dug*) are retrieved from lexical memory. On a single-mechanism view, the computation of both past tense types depends on associative memory. Neurological double dissociations between regulars and irregulars strengthen the duaNSl-system view. The computation of real and novel, regular and irregular past tense forms was investigated in 20 aphasic subjects. Aphasics with non-fluent agrammatic speech and left frontal lesions were consistently more impaired at the production, reading, and judgment of regular than irregular past tenses. Aphasics with fluent speech and word-finding difficulties, and with left temporal/temporo-parietal lesions, showed the opposite pattern. These patterns held even when measures of frequency, phonological complexity, articulatory difficulty, and other factors were held constant. The data support the view that the memorized words of the mental lexicon are subserved by a brain system involving left temporal/temporo-parietal structures, whereas aspects of the mental grammar, in particular the computation of regular morphological forms, are subserved by a distinct system involving left frontal structures.

Keywords: Language; Neurolinguistics; Brain; Grammar; Lexicon; Past tense; Regular; Irregular; Morphology; Aphasia; Agrammatism; Anomia; Declarative memory; Procedural memory; Dual-system; Single-system

1. Introduction

In the study of language, a fundamental distinction is drawn between the "mental lexicon" and the "mental grammar." The lexicon contains memorized pairings of sound and meaning. It must contain at least those words whose phonological forms and meanings cannot be derived from each other, such as the non-compositional word *cat*. It may also contain other non-compositional forms, smaller or larger than words: bound morphemes (e.g., the *-ed* past tense suffix, and the root *nomin* in *nominal* and *nominate*) and idiomatic phrases (e.g., *kick the bucket*). The grammar encompasses rules or constraints that govern the sequential and hierarchical combination

* Corresponding author.
E-mail address: michael@georgetown.edu (M.T. Ullman).

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of lexical forms into predictably structured complex words, phrases, and sentences. That is, the grammar subserves the computation of compositional linguistic forms whose meaning is transparently derivable from their structure. For example, a mental rule which specifies that English past tense forms are derived from the concatenation of a verb stem and an *-ed* suffix would allow us to compute past tenses from new words (e.g., *fax* + *-ed* → *faxed*) and from novel forms (e.g., *blick* + *-ed* → *blicked*). Rule-derived forms can thus be computed in real-time, and so do not need to be memorized—although even compositional linguistic forms (e.g., *walked*) could in principle be memorized in the lexicon (Berko, 1958; Chomsky, 1965, 1995; Pinker, 1994).

These two language capacities have been explained by two competing theoretical frameworks. "Dual-system" theories posit distinct cognitive or neural components for the two capacities (Chomsky, 1965, 1995; Damasio & Damasio, 1992; Fodor, 1983; Pinker, 1994). On this view, the learning, representation, and/or processing of words in a rote or an associative memory is subserved by one or more components, which may be specialized and dedicated ("domain-specific") to these functions (Bloom, 1994; Chomsky, 1965, 1995; Fodor, 1983; Forster, 1979; Levelt, 1989, 1992; Markman & Hutchinson, 1984; Pinker, 1994; Seidenberg, 1985; Swinney, 1982; Waxman & Markow, 1996). The use of stored words has been posited to depend especially on left posterior regions, particularly temporal and temporo-parietal structures (Damasio, 1992; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Dejerine, 1901; Geschwind, 1965; Goodglass, 1993; Lichtheim, 1885; Luria, 1966; Wernicke, 1874). The learning, knowledge, and/or processing of grammar are subserved by one or more components that are specialized and dedicated to their linguistic functions, and that have been posited to be innately specified (Chomsky, 1965, 1995; Fodor, 1983; Frazier, 1987; Pinker, 1994). The use of grammar has been claimed to be dependent on left frontal cortex, particularly Broca's area (the inferior left frontal gyrus, which contains the cytoarchitectonic Brodmann's areas 44 and 45 (Damasio, 1992)) and adjacent anterior regions (Bradley, Garrett, & Zurif, 1980; Caramazza, Berndt, Basili, & Koller, 1981; Damasio, 1992; Grodzinsky, 2000; Zurif, 1995), although this has been controversial, in particular regarding the comprehension of syntax (e.g., Hickok, 2000).

In contrast, "single-mechanism" (single-system) theories posit that the learning and use of the words and rules of language depend upon a single computational system that has a relatively broad anatomic distribution (Bates & MacWhinney, 1989; Elman, 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; MacWhinney & Bates, 1989; Rumelhart & McClelland, 1986; Seidenberg, 1997). This system is general-purpose ("domain-general") in that it also subserves non-language functions. There is no categorical distinction between non-compositional and compositional forms on this view. Rather, rules are only descriptive entities, and the language mechanism gradually learns the entire statistical structure of language, from the arbitrary mappings in non-compositional forms to the rule-like mappings of compositional forms. Modern connectionism has offered a computational framework for the single system view. It has been argued that the learning, representation, and processing of grammatical rules as well as lexical items takes place over a large number of inter-connected simple processing units. Learning occurs by adjusting weights on connections on the basis of statistical contingencies in the environment (Elman, 1996; Rumelhart & McClelland, 1986; Seidenberg, 1997).

Single and double dissociations which differentially link the lexicon to left posterior regions and aspects of grammar to left anterior regions suggest that these regions contain distinct neural underpinnings which play different roles in the knowledge or processing of the two capacities, as predicted by a dual system view. Such dissociations have been revealed by several experimental approaches.

Aphasia. There are at least two fundamental types of aphasia. These constitute an empirically demonstrated categorical distinction with respect to several behavioral and neuroanatomical dimensions. The dichotomy has variously been described as receptive/expressive, fluent/non-fluent, and posterior/anterior. Each label focuses on a different dimension of the aphasic impairment, such as whether it primarily affects input or output, how it affects speech production, and whether its associated lesions are in anterior or posterior portions of the left hemisphere (Alexander, 1997; Caplan, 1987, 1992; Dronkers, Pinker, & Damasio, 2000; Goodglass, 1993; Goodglass, Quadfasel, & Timberlake, 1964). Fluent aphasia involves speech that is facile in articulation and relatively normal in phrase length. It is associated with "anomia"—impairments in the production and reading of "content" words, such as nouns and verbs—and with deficits in the recognition of content word sounds and meanings. Fluent aphasics' lexical difficulties can be contrasted with their tendency to omit neither morphological affixes (e.g., the past tense *-ed* suffix) or "function" words, such as articles and auxiliaries, in their speech and reading. They also generally produce sentences whose syntactic structures are relatively intact. Fluent aphasia is strongly associated with damage to left temporal and temporo-parietal regions. Non-fluent aphasia involves speech that is effortful, with a reduction of phrase length and grammatical complexity. This "agrammatic speech" in non-fluent aphasia is strongly associated with impairments at producing appropriate morphological affixes (e.g., *-ed*) and function words. Non-fluent aphasics also often have difficulties using