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A study of syntactic processing in aphasia II: Neurological aspects

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Abstract

This paper presents the results of a study of the effects of left hemisphere strokes on syntactically-based comprehension in aphasic patients. We studied 42 patients with aphasia secondary to left hemisphere strokes and 25 control subjects for the ability to assign and interpret three syntactic structures (passives, object extracted relative clauses, and reflexive pronouns) in enactment, sentence–picture matching and grammaticality judgment tasks. We measured accuracy, RT and self-paced listening times in SPM and GJ. We obtained magnetic resonance (MR) and 5-deoxyglucose positron emission tomography (FDG PET) data on 31 patients and 12 controls. The percent of selected regions of interest (ROIs) that was lesioned on MR and the mean normalized PET counts per voxel in ROIs were calculated. In regression analyses, lesion measures in both perisylvian and non-perisylvian ROIs predicted performance. Patients who performed at similar levels behaviorally had lesions of very different sizes, and patients with equivalent lesion sizes varied greatly in their level of performance. The data are consistent with a model in which the neural tissue that is responsible for the operations underlying sentence comprehension and syntactic processing is localized in different neural regions in different individuals.

Keywords: Syntactic comprehension disorder; Localization of syntactic comprehension disorder

1. Introduction

Studies of the neurological mechanisms that support syntactic processing are based on deficit-lesion analyses and functional neuroimaging in normal subjects. Most studies are primarily directed at the question of where syntactic processing takes place in the brain.[1]

There is widespread agreement that some aspects of syntactic processing are based in the perisylvian association cortex of the dominant hemisphere (Caplan, Hildebrandt, & Makris, 1996; Mesulam, 1998). This region is often further subdivided into smaller areas that are said to be involved in syntactic processing, or in specific aspects of syntactic processing (e.g., Grodzinsky, 2000). "Broca's

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[1] We shall use the term "syntactic processing" in this paper to refer to both the representation and processing of syntactic information. The distinction between the representation of syntactic information and its processing is bound up with the issue of how to model syntax and its processing. Assuming that there is a distinction to be made between the representation of syntactic information and its processing, the usual arguments that a deficit affects a representation or processing could be made regarding these mental constructs. The arguments that a deficit affects a representation include the presence of the deficit in all tasks, item-specificity, preservation of superordinate information, and failure to respond to cuing; the opposite phenomena are said to indicate processing ("access") disorders. These arguments would have to be modified to apply to syntactic representations. For instance, item-specificity may find a counterpart in structure- or operation-specificity in the case of syntax. For the most part, aphasiological researchers in the Chomskian tradition have noted the distinction between the representation of syntactic information and its processing but not examined it empirically.

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area" and "Wernicke's area" are two such regions; the inferior parietal lobe is a third.

A reasonable description of the perisylvian region in gross anatomical terms that almost all researchers would endorse includes the pars triangularis and opercularis of the inferior frontal gyrus, the posterior portion of the superior temporal gyrus, the angular gyrus and the supramarginal gyrus. Many researchers also include more ventral parts of the inferior frontal lobe in this region and sometimes opercular parts of the inferior frontal gyrus. Many also include the entirety or the anterior half of the insula. Broca's area is almost always taken to include the pars triangularis and opercularis of the inferior frontal gyrus, but variable amounts of more ventral and opercular frontal cortex may be included. Wernicke's area is usually considered to include the posterior portion of the superior temporal gyrus, but has also been described as including the posterior portion of the superior temporal sulcus, the superior part of the posterior portion of the middle temporal gyrus and, in some writings, larger or smaller portions of the parietal lobe (see Bogen & Bogen, 1976; for review). The inferior parietal lobe is usually taken to be the angular and supramarginal gyri. These descriptions of these regions are themselves somewhat ill-defined, since some boundaries are not marked by sulci, but they give a reasonable idea of where many researchers have thought syntactic processing takes place.[2]

There is considerable disagreement regarding whether areas of the brain outside the perisylvian association cortex support syntactic processing, and, if so, what areas are involved in this function. A number of researchers hold the view that the left inferior anterior temporal cortex is involved. This opinion is largely based on functional neuroimaging data (Mazoyer et al., 1993; Noppeney & Price, 2004). Suggestions have also been made on the basis of functional neuroimaging data that superior parietal cortex is involved (Caplan, Alpert, & Waters, 1999; Osterhout & Holcomb, 1992). Subcortical gray matter structures have been suggested to be involved in aspects of syntactic processing. The leading candidates are portions of the basal ganglia (Damasio, Damasio, Rizzo, Varney, & Gersch, 1982; Ullman, 2001), portions of the thalamus (Mohr, Watters, & Duncan, 1975), and portions of the cerebellum (Fabbro, Moretti, & Bava, 2000).

The evidence that non-perisylvian regions are involved in syntactic processing is much weaker than the evidence for the involvement of the perisylvian association cortex in these processes. A complete review of all the data is beyond the scope of this paper, but, in a nutshell, all types of evidence—deficit-lesion correlations and functional neuroimaging based upon both vascular and electrophysiological responses—point to the involvement of the perisylvian association cortex in this function, whereas the evidence implicating other areas is much more often based on a single type of data and is, in some cases, subject to alternative explanations. For instance, the vascular lesions in subcortical areas seen on CT or MR that are associated with syntactic deficits are almost always associated with metabolic

[2] Macroscopically defined areas of the brain have specific functions, if they do, by virtue of their cellular content, including the type and distribution of neurons in each area, the receptors and neurotransmitters of these neurons, the secondary messenger systems that are active in them, etc., and the connectivity of the neurons in the area. The macroscopically defined areas identified above are thus assumed to be shorthand for regions of the brain that share unique physiological features that are relevant to their ability to encode and transform psychologically pertinent information. One approach to identifying such regions is on the basis of cellular morphology; i.e., cytoarchitectonic analysis. The most widely-cited cytoarchitectonic map in contemporary cognitive neuropsychology (perhaps the only map cited in contemporary cognitive neuropsychology) is Brodmann's (Brodmann, 1909). According to this map, the most constrained view of the perisylvian association cortex is that it includes Brodmann's areas (BAs) 45, 44, 22, 39, and 40; more expansive conceptions include all or parts of BA 46, 47, 21, 37, and even 10 and 11 although these last two areas, especially, are usually considered too far forward to be part of this area. Broca's area consists of BA 44 and 45; sometimes BA 46 and even less frequently BA 47 are considered part of Broca's area. Wernicke's area consists of BA 22 and possibly part of BA 21; the inferior parietal lobe of BA 39 and 40. Five points about the macroscopic and cytoarchitectonic areas in the perisylvian association cortex are important to note. First, there is considerable individual variation in the macroscopic neuroanatomy of these perisylvian gyri and sulci, in both the anterior and posterior parts of this region. The variability in the posterior portion of this region is perhaps better appreciated, as hemispheric differences in the size of regions such as the planum temporale and in the degree of ascent of the posterior portion of the Sylvian fissure (related to the size of the inferior parietal lobe) that have been widely discussed in relation to lateralization of language have drawn attention to individual differences in these areas, but the anterior portion of the region shows considerable (perhaps even as great) individual variability in the size and morphology of its constituent gyri and sulci (Geschwind & Galaburda, 1986). Second, Brodmann's areas are not isomorphic with macroscopically determined regions, such as gyri, sulci or lobes (Roland et al., 1997). Third, cytoarchitectonic areas show individual variability in their mapping onto gyri and sulci (Amunts et al., 1999). When this variability is superimposed on the degree to which normalization procedures applied to scan data distort individual macroscopic neuroanatomical cortical areas such as gyri and sulci, it becomes impossible to say exactly what cytoarchitectoic area is lesioned or activated in the great majority of studies involving the perisylvian association cortex. Fourth, Brodman's map is only one of many cytoarchitectonic maps. This map may not always divide the cortex into functionally distinct regions or be the only cytoarchitectonic map that does so. Finally, as noted above, cytoarchitectonically defined areas are based upon the distribution of cell types across identified layers of cortex. Other ways to divide neural tissue in terms of features that are potentially relevant to psychological operations, such as neurotransmitter systems, cross-cut cytoarchitectonic maps (Mazziotta et al., 2001). It is not clear at this point whether these ways to characterize neural tissue are more appropriate for purposes of localization of the functions studied here (or many other cognitive functions). Thus, the use of cytoarchitectonic areas is both too weak and too strong for purposes of empirical neuropsychological study. Their use is too weak because these regions are not unique among ways to divide neural tissue into areas that are potentially relevant to information-processing; their use thus does not capture other major physiological divisions of the neuraxis, such as into areas that share a neurotransmitter profile. On the other hand, the use of cytoarchitectonic regions as the basis for human cognitive functional localization is too strong because these regions are not reliably discernable at present; that is, they do not directly and invariantly align with macroscopic landmarks that are currently visible in in vivo images. For these reasons, in what follows, we will refer to macroscopically defined regions, not cytoarchitectonic areas, in our descriptions of brain regions and lesions. We recognize that this level of description does not, with some possible exceptions such as primary koniocortex, isolate brain regions that could play causal roles in well-articulated theories of the computational basis of cognitive functions. However, this level of description is the nearest one can come today to describing lesions in terms of divisions of the brain that might have such a status. We prefer the use of this level of description to one phrased in terms of cytoarchitectonic areas, which we believe exudes a false sense of confidence in the degree to which descriptions of lesion (or activation) sites are related to such theoretically pertinent divisions of the nervous system.