Syntax and Semantics, Neural Basis of

Intermediate article

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CONTENTS

Based on evidence from aphasia and neuroimaging studies, elements of syntax and semantics appear to be neurologically isolable and have distinct time courses.

INTRODUCTION

The neurology of syntax and semantics begins with a broad description of these two general areas of language. Syntax includes (a) phrasal geometry – the way in which lexical categories such as noun and verb project hierarchically to form phrasal categories such as noun phrases and verb phrases; (b) the 'dislocation' property of language whereby phrases that are pronounced, heard, or read in one position, are interpreted in a different, nonadjacent position; (c) lexical properties that have structural effects (e.g. the number and type of logical arguments or thematic roles a verb or noun entails); (d) binding relations – the distribution of pronouns, reflexives, and their antecedents (the noun phrases to which they co-refer); and (e) inflectional morphology and agreement. Syntax, then, is essentially about structure-building, from the word to the sentence. Semantics includes (a) the meanings or senses of words (known as lexical-semantics; more formally this may include lexical-conceptual structure); and (b) the meaning of the entire sentence, including its truth-value and logical form. Sometimes semantics also includes how the meaning of a sentence fits into the discourse of multiple sentences. (*See* **Binding Theory**; **Construction Grammar**)

Linguistic theory is concerned with characterizing a mental grammar – the set of abstract categories, rules and principles that underlies language. Accordingly, it has been suggested that a theory of a mentally represented grammar must be accountable to neurological data. The theory can be used as a set of 'discovery procedures', seeking whether elements of syntax and semantics are neurologically isolable. It is also often assumed that linguistic theory is directly relevant to the computational activity of the language processor, the latter being concerned with the study of the mental operations that compute, activate, and integrate linguistic information types. The neurology of language, therefore, involves concepts and methods from linguistics, cognitive psychology, neuropsychology, computer sciences, the neurosciences, and communicative disorders. (*See* **Language and Brain**)

There are two general methods in the study of the neurology of syntax and semantics and in the study of brain–language relations: behavioral studies and functional imaging. Behavioral studies typically use aphasia (that is, lesion studies) as a window into the normal system. Functional imaging techniques could be argued to be more directly aligned with neurology, and are designed to measure the localization of, and in some cases temporal unfolding of, aspects of language. These techniques include positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG), and the measurement of event-related potentials (ERPs) using electroencephalography. Though functional imaging has begun to bear empirical fruit, the study of brain–language relations has, as its bedrock, studies of language pathology subsequent to brain damage. (*See* **Aphasia**; **Electroencephalography (EEG)**)

EARLY LESION STUDIES

Syntactic and semantic analyses of aphasia have evolved from a theory of the localization of 'language as activities' as exemplified by the work of Wernicke, Lichtheim, and Geschwind. This theory focused on the dissociation of production and comprehension: the former was considered to be disrupted by left inferior frontal lesions involving motor association cortex (Broca aphasia) (Figure 1), the latter by left superior posterior temporal lobe lesions involving auditory association cortex (Wernicke aphasia) (Figure 1). From these findings it was assumed that language production depended upon principles of motor system organization and that comprehension depended upon principles of auditory perception. (*See* **Wernicke–Geschwind Model**; **Broca, Paul**)

Following Chomsky's groundbreaking work in theoretical linguistics, psycholinguists in the 1960s and 1970s began investigating brain–language relations in terms of abstract grammatical categories. In people with Broca aphasia, comprehension limitations were discovered that seemed to parallel production deficits: just as these patients tended to omit grammatical morphemes when speaking, so, too, were they unable to use them for the purpose of comprehension. Also in line with their syntactically simplified output, they were unable to carry out normal syntactic analyses on input strings, their comprehension at the sentence level thereby being abnormally reliant on semantic and plausibility cues. Taken together these findings suggested that damage to left inferior frontal cortex produced an overarching syntactic limitation, even as it spared the capacity to carry out semantic inference (Figure 1). In contrast, people with Wernicke aphasia did not show a normal capacity for semantic inference at the sentence level. Since these patients also tended to produce semantically empty speech in the context of what seemed to be normal syntax, it seemed reasonable to assign this cortical area the role of an amodal semantic center (Figure 1). (*See* **Government–Binding Theory**)

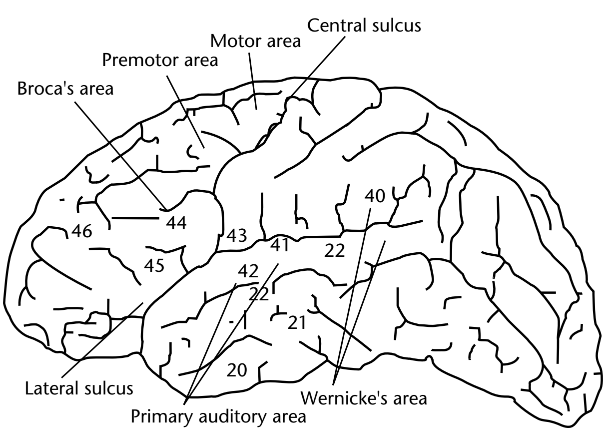

Figure 1. Lateral view of the left cerebral cortex, showing the cytoarchitectural boundaries and Brodmann's areas.

On further analyses in the 1980s and beyond, both functional distinctions (production–comprehension, and syntax–semantics) harvested some support from lesion studies. In what follows, the focus is primarily on comprehension. The language parts and the neurology are considered separately, beginning with an introduction to current psycholinguistic theories of normal language processing, those that are relevant to the study of brain–language relations.

MAJOR PSYCHOLINGUISTIC THEORIES

Just as a linguistic theory should be neurologically defensible, so, too, should hypothesitical processing operations be accountable to data gathered from both normal and language-impaired individuals. Current psycholinguistic theories (mostly concerned with comprehension) can be divided into two competing sets of accounts. Serial, form-driven accounts have a modular architecture and claim that syntactic processing proceeds initially independently from semantic and pragmatic considerations (e.g. Frazier and Clifton, 1996). One such account claims that a first-pass analysis of a sentence includes only placing the incoming lexical items into lexical categories, and, perhaps, activating lexical properties that have immediate structural implications (for example, whether a verb licenses one, two, or three arguments). Lexical categories are then set into phrases via simplicity heuristics: for example, 'build the smallest number of nodes'; 'attach the next lexical item to an already existing phrase'. Thus, only one possible parse is attempted at any given time. The second-pass analysis (or reanalysis if the first parse fails) uses contextual semantic and pragmatic information to identify the correct interpretation for the input. To complicate matters, there are also form-driven accounts that allow multiple syntactic parses in the case of syntactic ambiguities. (*See* **Language Comprehension**; **Psycholinguistics**; **Sentence Processing**; **Sentence Processing: Mechanisms**)

Unlike such form-driven accounts, highly interactive accounts claim that various processes (including syntax and semantics) interact continuously during comprehension. Syntax is considered mostly to be a second-order description for what are really concatenated lexical activation processes (e.g. MacDonald *et al*., 1994). One critical difference between the two accounts, then, is the initial influence of contextual, semantic and pragmatic influences: a form-driven account claims that initial processing is not influenced by such extrasyntactic information, whereas a highly interactive account claims that processing is continuously affected by multiple sources of information (with different types of information having different degrees of influence). Note that the highly interactive account has some intuitive appeal; after all, it is unarguable that all types of information interact to yield an interpretable sentence. However, the issue is not if information interacts during language processing, but when particular types of information are activated and integrated into the temporal unfolding of language processing. (*See* **Constraint-based Processing**)

To this end, psycholinguistic investigations sometimes make a distinction between offline and online tasks. Offline tasks are useful in studying coarse-grained characteristics of language processing; they are designed to collect data at the endpoints of processing after conscious reflection has occurred. Typical offline methods are untimed, and include sentence–picture matching tasks, grammaticality judgments, answering questions about a sentence, or paraphrasing that sentence. Online tasks collect 'processing time' data moment by moment as input is being analyzed; in particular, they are claimed to be sensitive to rapid, 'reflexive' and unconscious operations. Online tasks include crossmodal lexical priming techniques and word-by-word reading and eye-tracking.

Normal Lexical Processing

The battleground for the form-driven and highly interactive processing accounts has typically involved lexical (and also structural) ambiguities, as well as the dislocation property of sentences. Lexical ambiguities concern the processing of lexical items that have more than one meaning, and the subsequent resolution toward one of those meanings. For example, consider:

> The man saw several spiders, roaches and other bugs [1] in the corner [2] of his room.

The word 'bugs' is lexically ambiguous (ignore for the moment the effect of sentence context); it has (at least) two distinct meanings – 'insect' and 'listening device or hidden microphone'. Given the presentation of a sentence containing a noun (or any lexical item) that has multiple senses attached to one phonological or orthographic form, are one or all of the meanings activated, and when during the time course of sentence comprehension does that activation take place? The answer to these questions seems to indicate that at the point where the phonological/orthographic form of the ambiguous item is recognized, multiple senses are activated. Interestingly, these multiple senses are initially activated even in sentence contexts that appear to be biased toward one particular sense. So, given the example above, at probe position 1 – in the immediate temporal vicinity of the target 'bugs' – the 'insect' sense and 'hidden microphone' sense are both momentarily activated; it is only downstream from the target (position 2, roughly 750 ms later) that the contextually relevant meaning (that is, 'insect') remains active and the inappropriate meaning is suppressed. (*See* **Lexical Ambiguity Resolution**)

These results suggest that lexical access is initially form-driven; context effects and those based on real-world knowledge are seen to take place only subsequent to lexical access. Similar immediate, form-driven effects have been found for the activation of a verb's argument structure (the number of participants/noun phrases entailed by a verb).

Normal Syntactic Processing

The processing of dislocation ('discontinuous dependencies') has likewise reflected on the form-driven nature of initial language operations. Consider:

> The policeman saw <u>the boy</u> who the crowd at the party [1] accused _____ [2] of the crime.

Note that this complex sentence contains two underlying propositions: 'The policeman saw the boy' and 'The crowd at the party accused the boy of the crime'. Each underlying proposition suggests a subject–verb–object order (which is canonical in English). So, in the surface form of the complex sentence, the direct object of the verb 'accused' (that is, 'the boy') occurs prior to the verb, in a noncanonical position. Linguistic theories have various ways for dealing with such dislocation. For example, in a transformational framework the underlying direct object noun phrase (NP), 'the boy', has moved to a noncanonical position, leaving behind a trace or copy of itself at the post-verb position (signified by the gap). In psycholinguistic terminology, the moved NP (or the NP that is heard during auditory presentation) is called the 'filler', and the position from where it moved and where it is interpreted is called the 'gap'.

Presented with such structures, normal listeners indeed appear to interpret the dislocated NP at its canonical, postverb position (position 2 above), yet interpretation does not occur just prior to this position (at 1 above). Thus, the dislocated NP is reaccessed (see, for example, Love and Swinney, 1996). Like the lexical ambiguity work, gap-filling also appears to be a form-driven, automatic, reflexive operation, even when biasing semantic and contextual information is added. Consider:

> Everyone watched the enormous heavyweight boxer who the small 12-year-old boy on the corner had [1] beaten ____ [2] so brutally.

Even though real-world plausibility strongly suggests that 'the enormous heavyweight boxer' is not a plausible direct object for the verb 'beaten', 'boxer' is activated at the gap position (2), but not at the pregap position (1). This interesting property of language processing is also observed with other complex constructions, and it has been argued that lexical entailments and even probabilistic information do not seem to affect such automatic, initial processing routines.

LESION STUDIES: AN UPDATE

In the 1990s the lesion-localizing value of Broca and Wernicke aphasias continued to dominate the investigative landscape. Though lesion extent is often variable, the neurological damage underlying these two types of aphasia appears to be quite distinct: Broca aphasia involves cortical tissues which include the left frontal operculum (Broca's area) and insula, as well as subjacent white matter; Wernicke aphasia involves tissue that lies more posteriorly, in the left temporoparietal region inferior to the sylvian fissure (Figure 1). What, then, are the behavioral manifestations tied to these profiles that involve linguistic information types and their processing routines?

One influential set of accounts – the trace deletion hypothesis – has claimed that individuals with agrammatic Broca aphasia have a restricted syntactic deficit that disallows the normal representation of traces or copies of moved NPs. This deficit (essentially, a description cast in terms of linguistic theory) behaviorally manifests as an inability to comprehend only certain sentence structures (e.g. passives, object relatives and object clefts), while sparing others (e.g. actives, subject relatives and subject clefts). The empirical support for this account has come primarily from patterns of sparing and loss seen on offline tasks such as sentence–picture matching and grammaticality judgments. Thus, the claim is that the neural tissue implicated in Broca aphasia is used to support the computation underlying dislocation – of transformational relations between moved NPs and their extraction sites – and is not used for any other 'syntactic' or lexical activity (Grodzinsky, 2000). Unlike the interpretable sentence comprehension patterns evinced in Broca aphasia, Wernicke aphasia results in variable, often uninterpretable behavior. When these behaviors are interpretable, however, they suggest a lexical-semantic deficit that does not overlap to any significant extent with syntax or with that of Broca aphasia. There is also considerable online evidence for a distinction between Broca aphasia and Wernicke aphasia, related grossly to the syntax–semantics partition. Zurif and colleagues in a series of online examinations found that people with Broca aphasia do not reaccess fillers at their gap site. Processing a sentence continues without the normal link established between the NP and its extraction site, resulting in offline comprehension difficulties (e.g. Zurif *et al.*, 1993). Individuals with Wernicke aphasia show normal, on-time reaccess effects. Furthermore, though it has also been claimed that lexical deficits cause the syntactic limitations in Broca aphasia, the activation of lexical properties (specifically, verb–argument structure) is intact in Broca – and not Wernicke – aphasia, and therefore independent from observed syntactic limitations (e.g. Shapiro *et al.*, 1993). These online data also suggest that it may not be syntactic processing that is served by Broca's area and surrounding tissue, but rather that this brain region may provide the resources necessary for carrying out fast-acting, reflexive operations that happen to underlie structural processing.

Other Ways to Cut the Language Pie

The interpretation that either (a) a restricted syntactic deficit underlies Broca aphasia while people with Wernicke aphasia evince a lexical-semantic deficit, or (b) reflexive, automatic processing routines are disrupted in Broca aphasia, has not gone unchallenged. The relevant opposing claim is that attempting to generalize sentence comprehension patterns to individuals with Broca aphasia is misguided because of the heterogeneous nature of the behavioral patterns observed in these individuals, and because of the wide-ranging cortical and subcortical damage associated with Broca aphasia. This claim suggests a more 'holistic' approach to language representation and processing in the brain; on this account the apparent linguistic-specific deficits are more likely to be explained by deficits in general cognitive abilities, though these 'abilities' (e.g. working memory, attentional resources) remain relatively undefined.

It would seem, then, that this domain-general account of language deficits is at complete odds with a localizationist, language-specific account. Certainly the underlying assumptions are at odds: the linguistic distinction account suggests that brain regions are specialized for particular language operations, while the holistic account claims that language emerges from the conjoint activity of spatially discontinuous and widely distributed brain regions. The evidence from neuroimaging might help to resolve some of these issues; indeed, this evidence suggests that the lesion studies have been on the right track – that syntactic and semantic operations recruit different neuroanatomical regions, and, critically, have distinct time courses.

FUNCTIONAL NEUROIMAGING AND EVOKED-POTENTIAL STUDIES

Recent technological advances have demonstrated that neuroimaging and electrophysiological examinations have important potential. Each technique has its limitations: PET has fair spatial resolution (10 mm or more) but poor temporal resolution (approximately 30 s); fMRI has excellent spatial resolution (less than 5 mm) but temporal resolution is moderate (approximately 1 s). Evoked potentials have excellent temporal resolution (in ms), but comparatively poor ability to locate the neural generators of electrical activity in the brain (within about 20 mm).

Positron Emission Tomography

Positron emission tomography involves taking images of regional cerebral blood flow after injection of a radiopharmaceutical tracer such as water labeled with oxygen-15. It thus can be used to see which areas of the brain 'light up' during overall sentence interpretation. Caplan and colleagues have produced a series of such studies, examining sentence structures like right-branching subject gaps (e.g. 'the child spilled the juice that stained the rug') and center-embedded object gaps (e.g. 'the juice that the child spilled stained the rug'). These studies show that the left perisylvian cortex (pars opercularis of Broca's area) is activated in complex (object gap) structures, while Wernicke's area is not (see, for example, Caplan *et al.*, 2000).

Functional Magnetic Resonance Imaging

Functional magnetic resonance imaging exploits the local magnetic properties of brain tissue. When the person to be investigated is placed in a magnetic field, the proton nuclei of hydrogen atoms align themselves within the field and move about in random orientation to one another. A brief electromagnetic pulse is introduced which disturbs the nuclei and results in their coherent orientation. This coherence is detected as a radio signal and is formed into an image. Blood can be used as an endogenous contrast agent which allows the measurement of the hemodynamic response to event-related (that is, stimulus presentation) activities. Taken as a whole, fMRI studies indicate that different neural regions appear to support different linguistic information types.

Event-related Brain Potentials

Event-related brain potentials record the electrical activity of the brain time-locked to an external event (in the present case, time-locked to word or sentence input). Like many of the neuroimaging techniques, it is common practice to use the detection of different types of linguistic errors, and the resultant ERPs are measured in terms of their amplitude, latency and (in some cases) distribution. The ERP has been extensively used to study language processing. The N400 – a negative waveform occurring approximately 400 ms after presentation of relevant stimulus – is typically used as a marker for semantic processing, following the groundbreaking work of Kutas, Hillyard and their colleagues (Kutas and Hillyard, 1983). It is likely that the N400 is elicited in response to the semantic or pragmatic expectation of a given word in a particular sentence context, with large N400s found when the word is semantically anomalous. (*See* **Event-related Potentials and Mental Chronometry**)

Syntactic processing has been associated with two distinct waveforms, a late and large positive wave shift (the P600), and a left anterior negative (LAN) wave. The P600 has been found with various types of syntactic violations, such as phrase structure and agreement errors, and appears to be associated with second-pass reanalysis routines. Friederici and colleagues (e.g. Friederici, 1995) have specifically tied their work to models of normal sentence processing. They have suggested a two-stage serial processor whereby first-pass parsing routines are highly automatic and reflexive, and are reflected by an early LAN wave, and that controlled, second-pass reanalysis routines are reflected by the P600.

Magnetoencephalography

A newer electrophysiological technique, magnetoencephalography, has similarly good temporal resolution, and significantly better spatial resolution than ERPs, but is limited by only detecting signals from areas of cortex that lie perpendicular to the scalp. Thus far, MEG has been used mostly to examine phonetic and acoustic variables (the latter has been directly compared, favorably, to the detailed data obtained from invasive electrode recordings in other animals).

Summary of Aphasia and Neuroimaging Data

Though neuroimaging and electrophysiological techniques have yielded important information about brain–language relations, it could be argued that the fuel for these studies has been investigations of language processing in both normal and brain-damaged individuals. To be sure, there are limitations to both methods. Evidence from brain damage is, by its nature, imprecise. Theoretical differences, stimulus characteristics, task considerations, subject selection, and perhaps individual variation, combine to sometimes yield conflicting data. Neuroimaging has attempted to provide greater precision regarding localization of function, but it turns out that there is considerable variability regarding strict localization of syntactic and semantic processing here as well, and localization of semantic processing is typically computed by reference to semantic anomalies or simple lexical access, which are at best rough attempts at semantics.

Nevertheless, by combining lesion studies with neuroimaging techniques, scientists have begun to unravel the temporal and spatial characteristics of language representation in the brain (Figure 1). These characteristics may include:

- acoustic information that is analyzed in the auditory cortex within 100 ms of stimulus onset;
- identification of phonological word forms and phonological sequencing, which recruits left planum temporale and also involves the upper and posterior parts of Broca's area;
- lexical category formation that occurs within 200 ms of onset, and moves from Wernicke's area (Brodmann's area 40) to the inferior part of Broca's area (Brodmann's area 44), the latter supporting initial structure-building – including dislocation processing;
- lexical-semantic activation and integration, which involves the temporal language region (Brodmann's areas 22 and 21) and occurs within 300–500 ms of onset;
- reanalysis of input (if necessary), which occurs within approximately 600–1000 ms of onset and probably recruits areas involved in working memory (e.g. Brodmann's area 46) and regions including the right hemisphere as well (see Friederici, 1995).

RECOVERY, TREATMENT AND NEUROIMAGING

Recovery from brain damage is just beginning to be seriously studied by scientists interested in brain–language relations. The issues confronting these investigations are particularly thorny, since brain organization, learning or relearning, and several facets of language are involved. In particular, careful attention has to be paid to the research designs and methods that yield and measure learning over time. Although there are many published studies on the treatment of language disorders through the fields of communicative disorders and the neuropsychology of language, very little of this work has been concerned with the sorts of specific syntactic and semantic deficits observed in the aphasias (but see, for example, Thompson *et al.*, 1997). Fewer still have exploited neuroimaging techniques to map the purported recovery process. One broad issue is whether perilesional tissue or right hemisphere homologs (of, for example, Broca's and Wernicke's areas) appear to be active during good or poor recovery from aphasia. The evidence is equivocal, and is limited by the large differences in methods and participant selection.

SYNTACTIC PRODUCTION

Most of this discussion has been on how comprehension – normal and disordered – reflects on the neurology of syntax and semantics. There have been few similar efforts in syntactic production, even though the hallmark of Broca aphasia has always been effortful, halting and syntactically impoverished speech. The most recent work in production deficits in Broca aphasia from a linguistic framework suggests that phrasal geometry and its relation to abstract inflection features of language may be involved in a description of the deficit. Within that part of syntactic theory that deals with the phrase structure tree (which describes the structural configuration of sentences), lexical categories such as noun, verb, preposition and so on are said to 'project' upwards in the tree to maximal projections (e.g. noun phrases, verb phrases, prepositional phrases and so on). Careful analyses of agrammatic speech have yielded a circumscribed syntactic deficit: the sentence structures do not project to the topmost part of the tree, resulting in a production impairment of some sentence constructions in English (e.g. *wh*-questions, tenseless verbs), while different constructions that rely on the same part of the tree in other languages are affected (e.g. Friedmann, 2002). These sentence production results highlight the apparent importance of Broca's area for the normal functioning of syntactic abilities that are quite distinct in production versus comprehension; thus far, a description encompassing an overarching syntactic deficit has not been satisfactorily proposed.

CONCLUSION

The study of brain–language relations has benefited greatly from work in theoretical linguistics, psycholinguistics, lesion studies, and functional neuroimaging. Elements of syntax and semantics – the former more specified than the latter – appear to recruit different brain regions as well as distinct time courses, although some overlap has been observed. This localizationist hypothesis in one form or another has been with us in the modern era for at least 150 years (as has been its counterpart, the holist approach); we are now beginning to fill in some of its details.

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Systematicity

See **Connectionism and Systematicity**