Sentence Comprehension in Aphasia

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Abstract

Aphasia is a disorder of language that sometimes occurs in the setting of brain damage. Aphasic disturbances of syntactic comprehension have been described only in recent decades, and have been characterized as the loss of the ability to understand non-canonical sentences. Several interesting hypotheses have been advanced to explain this phenomenon. Some of these hypotheses rest on the assumption that heuristics play a role in producing the aphasic comprehension pattern. Evidence from the past decade suggests that heuristic processes do play a role in normal sentence comprehension, and act in concert with slower processes that more closely resemble the syntax of linguistic theory. The slower syntactic mechanisms appear to be more readily disturbed by brain damage, leading to greater difficulty with sentences that cannot be interpreted heuristically. However, the dichotomy between canonical and non-canonical sentences accounts for little of the variance in the performance of aphasic individuals. Instead, the comprehension of each sentence structure is disrupted according to the complexity of the structure and the severity of the individual’s aphasia. This observation argues against hypotheses that posit a deficit of a specific linguistic operation and favors reduction of a hypothetical cognitive resource that is necessary for normal comprehension. In this case, the chief contribution from linguistic theory is the syntactic tree itself, which affords a concise characterization of the difficulty of parsing and interpreting a given sentence. The field now faces several challenges. The neural basis of heuristic, parsing, and interpretive mechanisms must be elucidated. Achievement of this objective entails a neural characterization of the cognitive resource that is disrupted in sentence comprehension disorders and of the semantic representations onto which morphemes and sentences are mapped.

Introduction

APHASIA

Aphasia is an acquired disorder of language that is caused by brain damage. Common causes of aphasia include stroke, trauma, brain tumor, and neurodegenerative diseases. Clinicians who care for patients with aphasia routinely classify patients parametrically according to the presence or absence of impairment of four gross linguistic skills: naming, fluency, repetition, and comprehension. Each of these parameters is a complex language act that requires numerous processing steps, all of which are supported by a distributed network of neurons. Naming impairment of some sort is assumed to be universal among patients with aphasia, while relative sparing or impairment of the other three abilities yields eight clinical categories of aphasia that have more or less well-defined cerebral localizations (see Table 1) (Damasio 1992; Mendez and Clark 2008).

Linguists impose divisions on language which differ greatly from the parameters that generate the clinical taxonomy of aphasic disorders. Linguistic theory breaks language behavior down according to levels of representation, including phonetics, phonology, morphology, syntax, semantics, and pragmatics. Any given aphasic individual may exhibit

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deficits which impact several levels of linguistic representation. This review focuses on syntax, which is generally considered to be ‘central’ to language function, constituting a sort of interface between sounds and meanings. Due to the functional interposition of syntax between sound and meaning, the discussion of sentence comprehension deficits in the literature often encroaches on the syntax-like field of morphology (the grouping of meaningful sound segments into words), and on the more abstract field of semantics (the representation of linguistic meanings in the mind).

The study of brain-language relationships would be greatly simplified if there were anatomically defined neural centers that transparently supported clinical aphasia parameters (e.g., fluency or naming) or levels of linguistic representation (e.g., phonology or syntax), but this is not the case. Instead, the brain comprises a vast network of microscopic neurons, all of which are processing information simultaneously and transmitting results to other neurons. During the last 30 years a view of the global organization of the brain has emerged that blends localizationist views (in which parts of the brain are devoted to single, complex functions) with equipotential views (in which the entire brain could be involved in any function). The dominant view among neurologists is that cognition results from the activity of large-scale, partially distributed networks (Mesulam 1990).

Table 1. Eight types of aphasia, defined by four parameters of spoken/auditory language performance. All aphasia syndromes listed here are associated with impaired naming, but the other three parameters may be relatively spared or impaired. ‘X’ indicates relative impairment; ‘ok’ indicates relative sparing.

<table>
<thead>
<tr>
<th>Syndrome</th>
<th>Naming</th>
<th>Fluency</th>
<th>Repetition</th>
<th>Comprehension</th>
<th>Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anomic</td>
<td>X</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
<td>Almost anywhere in the cerebral cortex, left hemisphere more likely</td>
</tr>
<tr>
<td>Broca’s</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>ok</td>
<td>Usually anterior, especially inferior frontal</td>
</tr>
<tr>
<td>Wernicke’s</td>
<td>X</td>
<td>ok</td>
<td>X</td>
<td>X</td>
<td>May involve posterior superior and middle temporal gyri, inferior parietal regions</td>
</tr>
<tr>
<td>Conduction</td>
<td>X</td>
<td>ok</td>
<td>X</td>
<td>ok</td>
<td>Inferior parietal, superior temporal sulcus, subcortical white matter</td>
</tr>
<tr>
<td>Transcortical sensory</td>
<td>X</td>
<td>ok</td>
<td>ok</td>
<td>X</td>
<td>Posterior watershed region between territories of middle and posterior cerebral arteries; involves parieto-occipital and tempo-ro-occipital regions</td>
</tr>
<tr>
<td>Transcortical motor</td>
<td>X</td>
<td>X</td>
<td>ok</td>
<td>ok</td>
<td>Either large dorsolateral frontal or mesial frontal, involving supplementary motor area and anterior cingulate gyrus</td>
</tr>
<tr>
<td>Transcortical mixed</td>
<td>X</td>
<td>X</td>
<td>ok</td>
<td>X</td>
<td>Large, possibly outlining the perisylvian region through involvement of watershed zones anterior and posterior to area supplied by MCA</td>
</tr>
<tr>
<td>Global</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Large, involving majority of left perisylvian region</td>
</tr>
</tbody>
</table>

MCA, middle cerebral artery.
Each neuron is relatively specialized for processing a certain kind of information, such as sounds within a narrow frequency range, lines of a certain orientation, or more complex stimuli such as faces or entire words. Situating neurons with similar response properties close together reduces the total volume of wiring connections and might render the system more efficient (Buzsaki, et al. 1991; Chklovskii and Koulakov 2004). Tight groups of neurons that process the same kind of information form anatomically distinct nodes in a given cognitive network. Selective linkage of distant nodes permits the binding together of distinct streams of information, and results in the overall structure of a small-world network (Bassett and Bullmore 2006; Watts and Strogatz 1998). Language functions are supported by a vast cerebral network, most of which is situated in the left hemisphere, around the sylvian fissure (Caplan et al. 1996). Brain lesions that impact linguistic or syntactic performance are usually located in this region.

AGRAMMATISM

Aphasiologists commonly refer to morphological or syntactic linguistic disturbances as agrammatism. The term has been in use since the late 19th century and is used to describe the language output of certain (but not all) non-fluent patients (Goodglass 1993). Agrammatic individuals suffer from a deficit of language production at the level of phrases or sentences. Their speech is effortful and consists of brief phrases that contain mainly nouns, often with omission of grammatical features such as auxiliary verbs, prepositions, or inflectional morphemes (Damasio 1992; Goodglass 1993).

Caramazza and Zurif are the first to apply the term agrammatism to faulty language comprehension in their report of a dissociation that pertains to language understanding at the level of phrases or sentences (Caramazza and Zurif 1976). Specifically, they find that patients with certain aphasic syndromes, who initially appear to have intact auditory comprehension, actually have difficulty understanding the specifics of semantically reversible, non-canonical sentences. The experiment involves the presentation of sentences with center-embedded relative clauses, similar to sentences (1–4), below.

(1) The boy that eats the apple is wearing a green shirt.
(2) The boy that kicks the girl is wearing a green shirt.
(3) The apple that the boy eats is green.
(4) The boy that the girl kicks is wearing a green shirt.

The subject and the contents of the relative clauses from sentences (2) and (4) are semantically reversible, because boys may kick girls or vice versa. Sentences (3) and (4) are non-canonical, because they do not follow the typical subject-verb-object (SVO) word order of English. However, only (4) is both semantically reversible and non-canonical. Caramazza and Zurif report that when patients with Broca’s aphasia or conduction aphasia are asked to select a picture (from several distracters) that accurately depicts the meaning of this type of sentence, they often confuse who is doing the kicking and who is being kicked (a process referred to as ‘thematic role assignment’), and generally perform at a level that does not differ statistically from chance. They surmise that language comprehension processes include both simple rules that may be applied to a string of words (heuristics) and processes that act on a more complex mental representation of groups of words (which they term algorithms). They suggest that these aphasis patients suffer from disruption of syntax-like algorithmic processes, and that the unchecked heuristic processes lead the patients to false conclusions regarding the meanings of the sentences, particularly.
the assignment of thematic roles. The general pattern of agrammatic comprehension has been observed with other non-canonical structures, such as passive voice sentences (see, for example, Grodzinsky 2000b).

Despite the attraction of syntactic explanations for agrammatic comprehension, however, patients with this pattern of comprehension performance appear to have preserved sensitivity to syntactic structure. Specifically, they retain the ability to make accurate judgments of sentence grammaticality, at least with certain sentence structures (Linebarger et al. 1983; Wilson and Saygin 2004). In light of this discovery, Linebarger et al. (1983) propose two ideas to explain the agrammatic comprehension pattern. The first is that agrammatic patients are able to construct syntactic representations, but are unable to use these representations to derive sentence meaning. The second idea is that the patients suffer from a resource limitation that results in a combination of reduced parsing efficiency and reduced capacity for compositional semantic interpretation, such that different tasks produce qualitatively different patterns. That is, when subjects are not required to make semantic judgments on sentences, they are able to devote more resources to accurate syntactic analysis. The dissociation between syntax comprehension and grammaticality judgments remains a topic of debate.

THE MODERN APPROACH TO THE STUDY OF APHASIA

Two important developments in the previous century set the stage for the modern psycholinguistic approach to studying syntax in the brain. First, Noam Chomsky revolutionized the study of linguistics by rejecting behaviorism and introducing elements of formal language theory to characterize mental representations of syntactic structures (Chomsky 1957, 1959). The goals of linguistics are generally couched in computational terms (e.g., to devise a formal system that generates all and only the sentences of human languages), and most linguists consider language itself to be their object of study, rather than the minds that use language or the neural tissue that gives rise to it. Nevertheless, linguistics provides a foundation for language description that is essential for evaluating aphasia and for designing experiments that seek to elucidate relationships between language and the brain. Basic grammatical constructs, such as nouns and verbs, are now known to be differentially impacted by brain damage and to be supported by anatomically dissociable cortical networks (Bak et al. 2001; Hillis et al. 2002, 2004). It remains to be seen, however, which abstract theoretical constructs that have been devised by linguists are suitable for generating or evaluating neuroscientific hypotheses.

Second, as described above, Caramazza and Zurif (1976) discovered that patients with Broca’s or conduction aphasia exhibit difficulty assigning thematic roles in sentences with object-relative clauses, despite continuing to perform well with subject-relative clauses. This finding has been replicated and extended, and has led researchers to pose a number of interesting questions pertaining to the neural and computational bases for sentence production and comprehension.

Agrammatic Comprehension

THE TRACE DELETION HYPOTHESIS AND THE DOUBLE DEPENDENCY HYPOTHESIS

Most investigators use abstractions from linguistic theory to characterize or explain the pattern of deficits of comprehension among agrammatic individuals. The Trace Deletion Hypothesis is one such approach, and probably generates more discussion and controversy
than any other single hypothesis (Beretta and Munn 1998; Beretta, Pinango, Patterson, & Harford, 1999; Berndt et al. 1997; Caplan et al. 2006; Caramazza et al. 2005; Drai and Grodzinsky 2006; Grodzinsky 2000a,b). The term ‘trace’ refers to a phonologically null element in the syntactic representation that occupies the former position of a syntactic constituent that has been moved to another location in the sentence. For example, some linguistic analyses of sentence (4), repeated here, include a trace following the verb ‘kicks’, which is decorated with the same subscript (co-indexed) with the moved element ‘the boy’.

(4) The boy, that the girl kicks, is wearing a green shirt.

From a psychological standpoint, the implication is that when normal subjects listen to a sentence, they unconsciously construct a syntactic representation that describes the dependencies among the constituents of the sentence. Since traces are phonologically null, their presence must be inferred from other cues in the signal (e.g., the presence of the complementizer ‘that,’ and the absence of an object following the verb ‘kicks’). Traces must then be linked or associated with appropriate moved constituents in the sentence in order for the listener to derive the correct meaning from the sentence. Syntacticians represent this mental association with co-indexation.

Grodzinsky (1995a,b, 2000a,b) proposes that the deficit underlying agrammatic comprehension is the deletion of traces from the syntactic representation. Thus, when individuals with agrammatic aphasia hear sentence (4), they are unable to establish a link between the verb ‘kicks’ and the moved constituent ‘the boy’. These patients maintain knowledge of the meaning of ‘kick’, including the fact that it takes two arguments (an agent who kicks and a theme or patient that gets kicked). However, in the absence of normal syntactic mechanisms, Grodzinsky argues that they follow a ‘default’ (heuristic) strategy in which they always assign the agent role to the first noun phrase (NP) in the sentence. (For an explication of the default strategy, see Grodzinsky 1990: 97). If a subsequent NP is assigned the role of agent through intact syntactic mechanisms, they are led to the conclusion that there are two agents, and then are left with no option but to guess. Sentences with fewer moved elements or with only vacuous movement (such as active voice sentences and sentences with subject-clefts or subject-relative clauses) are therefore comprehended fairly well, while those in which movement disrupts the canonical word order of the sentence are comprehended poorly. Thus, performance falls to chance level on passive voice sentences and sentences with object-clefts or object-relative clauses. The TDH captures much of the observed data from sentences with theoretically moved constituents.

One source of controversy around the TDH regards the specifics of the default strategy. Part of the argument against the use of the default strategy is that such heuristics are not a part of syntactic theory. This criticism loses some of its force in light of more recent psycholinguistic evidence that normal sentence comprehension is facilitated by heuristic strategies (Ferreira 2003; Ferreira and Patson 2007; Ferreira et al. 2002; Townsend and Bever 2001). A more specific objection is that the default strategy, as defined by proponents of the TDH, should lead agrammatic patients to interpret verbs in certain sentence structures as having two agents. Thus, one might expect an aphasic person using this strategy (to interpret a non-canonical sentence) to prefer pictures in which both NP referents are performing an action over pictures that correctly depict the event. This prediction is not supported by experimental work in which individuals with agrammatic comprehension are tested with materials that allow for this choice. The agrammatic
individuals rarely select the double-agent pictures (Beretta and Munn 1998). In addition, the default strategy causes the TDH to make incorrect predictions regarding the interpretation of certain passive constructions in Venezuelan Spanish (Beretta et al. 1999).

The Double Dependency Hypothesis (DDH, Mauner et al. 1993) has been advanced with the goal of explaining the agrammatic pattern of performance without resorting to heuristic strategies that have not been a part of the traditional linguistic theory. According to this hypothesis, patients with agrammatism are unconstrained when co-indexing dependencies in the syntactic representation. This lack of constraint does not affect the interpretation of sentences with only one referential dependency, such as simple active voice sentences and subject-clefts. However, it leads agrammatic individuals to ambiguous conclusions when attempting to understand sentences with two or more referential dependencies, such as object-relative sentences. For example, consider sentence (4) once more, now decorated further with an additional trace motivated by the Verb Phrase-Internal Subject Hypothesis (Koopman and Sportiche 1991). (For a version of the TDH that takes into account the VP-Internal Subject Hypothesis, see Hickok et al. 1993).

(4) The boy\textsubscript{i} that the girl\textsubscript{j} kicks\textsubscript{i} is wearing a green shirt.

This sentence requires the listener to establish two chains of referential dependencies (shown here enclosed in angle brackets):

(5) \langle[the boy]\textsubscript{i}, t\textsubscript{i}\rangle and \langle[the girl]\textsubscript{j}, t\textsubscript{j}\rangle

According to the DDH, however, patients with agrammatic comprehension are not constrained by normal co-indexation patterns when establishing chains and therefore produce the following aberrant chains in addition to the correct ones:

(6) \langle[the boy]\textsubscript{i}, t\textsubscript{j}\rangle and \langle[the girl]\textsubscript{j}, t\textsubscript{i}\rangle

The aphasic person, faced with these two contradictory possibilities, is therefore required to guess which one is correct, and therefore performs at ‘chance’ level on non-canonical material. Subject-relative sentences and other canonical constructions have only one relevant dependency that requires co-indexation. Because no ambiguity is generated for these sentences, patients perform ‘above chance’.

While the DDH has the advantage of a stronger foundation in theoretical syntax (i.e., no requirement for atheoretical heuristics), and partitions the data from scrambled passives in Venezuelan Spanish appropriately (Beretta et al. 1999), evidence from two Mandarin Chinese-speaking aphasic individuals offers some support to the TDH (Su et al. 2007), or at least supports the use of heuristics in deriving sentence meaning. The study of Mandarin Chinese is important, because it happens that the TDH and the DDH make opposite predictions regarding the comprehension of relative clauses in Mandarin. As in English, when analyzed with the VP-Internal Subject Hypothesis, the Mandarin object-relative sentence is expected to have two referential dependencies. The DDH therefore predicts that individuals with agrammatic aphasia will perform at chance on this structure, but above chance on subject-relative sentences. However, although Mandarin is an SVO language, relative clauses in Mandarin precede the head noun, while relative clauses in western languages typically follow the head noun. Sentence (7) is an example of a Mandarin subject-relative sentence, and sentence (8) is an example of a Mandarin object-relative sentence (see sentences 7 and 8).
Because of this difference in relative clause placement, Mandarin subject-relative sentences are non-canonical, while object-relative sentences are canonical. For Mandarin, therefore, the TDH predicts worse performance with subject-relative sentences than with object-relative sentences, a reversal of the pattern predicted by the DDH. The authors observe the pattern predicted by the TDH in two out of six Mandarin-speaking individuals with aphasia, but do not observe the pattern predicted by the DDH.

Further evidence that heuristic processes play a role in sentence comprehension arises from Su, Lee, & Chung's (2007) observations of patient performance when interpreting the predicate adjectives of Mandarin sentences like (7) and (8) or their English translations. Note that both Mandarin sentences (7) and (8) contain the substring ‘cat very small’, which has a meaning consistent with the meaning of the matrix clause. In contrast, the English translation of sentence (7) contains the substring ‘the dog was very small’ (which has a meaning quite different from the meaning of the matrix clause). The presence of these local sequences may provide a simple explanation for the observation that Mandarin patients perform well on interpretation of the predicate adjectives for both sentence structures, while English-speaking patients exhibit difficulty interpreting predicate adjectives in the matrix clause of center-embedded subject-relative sentences (Hickok et al. 1993).

RESOURCE REDUCTION

A separate body of work, largely due to David Caplan et al. suggests that sentence comprehension failure that occurs in the setting of aphasia is the result of a single defect: specifically, a shortage of some resource that supports the computational processes necessary for constructing syntactic representations and deriving interpretations of them. One possibility for this resource is a specialized subset of verbal working memory (Caplan and Waters 1999), but other possibilities have been suggested (Caplan 2006; Caplan et al. 2007). This approach contradicts the more linguistically-motivated hypotheses, each of which implicates damage to a specific feature of the grammar (e.g., trace deletion). A consequence of this specificity is that these hypotheses predict that agrammatism will impact sentences with certain syntactic structures, while other sentences will not be affected. In contrast, the resource reduction hypothesis predicts that all sentences will be affected by aphasia to varying degrees, depending on their overall complexity.

Several lines of evidence support the resource reduction hypothesis (Caplan, Hildebrandt, & Makris, 1996; Caplan 2006; Caplan et al. 2007). First, split-half reliability estimates reveal higher correlations across sentence types than within sentence types. Linguistic-specific hypotheses predict the opposite pattern, with scores on affected sentence types showing the strongest correlations. Second, factor analysis of the performance of groups of individuals with aphasia reveals that most of the variance is explained by a single factor on which all sentence types load. Linguistic-specific hypotheses, in contrast,
predict that only affected sentences should load on the first factor. Third, ANOVA reveals an interaction between the overall level of patient performance (reflecting resource availability) and sentence type (reflecting resource demands). In addition, an individual’s aphasic syndrome (e.g., Broca’s aphasia) does not seem to predict any particular pattern of sentence comprehension deficit (Caplan et al. 2007). Specific linguistic hypotheses do not predict strong task effects, yet performance on different sentence comprehension tasks may vary substantially within individuals (Cupples and Inglis 1993; Caplan et al. 2007; Salis and Edwards 2009). Both the DDH and the TDH imply that performance on certain structures falls to chance levels because subjects are incapable of computing certain structures and therefore guess. However, evidence from eye-tracking (Dickey and Thompson 2009) and from self-paced reading (Caplan et al. 2007) reveals that aphasic individuals exhibit evidence of normal processing on the occasions when they answer correctly. This suggests that aphasia disrupts language processing without completely blocking specific linguistic computations, and that a component of randomness or stochastic noise may be necessary to explain variability in performance within individuals. A further line of evidence arises from studies in which non-brain damaged individuals are made to perform language comprehension or grammaticality judgment tasks with spectrally and temporally degraded auditory input. The performance of these subjects on a range of sentence structures is quantitatively similar to the performance of aphasic subjects with the same (undegraded) sentence material (Wilson et al. 2003; Dick et al. 2003).

THE TREE PRUNING HYPOTHESIS AND SYNTACTIC HIERARCHIES

Neither the TDH nor the DDH can account for other observations of agrammatic comprehension performance that can be parsimoniously addressed by considering the hierarchical constituent structure of syntactic trees. Patients with agrammatic comprehension generally perform worse on sentences with non-canonical word order than on sentences with canonical word order, but this dichotomy accounts for only a fraction of the variability seen among sentence structures. For example, Friedmann (2006) points out that (across several studies), object-relative sentences are significantly more difficult to comprehend than passive voice sentences. This distinction can be easily explained by taking into account the fact that object-relative sentences are more deeply embedded than passives [although number of propositions might have explanatory value as well, see Caplan et al. (1998) and Caplan et al. (1997)]. Thus, if the syntactic tree is ‘pruned’ at the level of the tensed or agreement phrase (TP or AgrP), patients will fail to build a representation that contains the relative clause, which requires projection to the complementizer phrase (CP, located above the inflectional phrases in the tree – see Figure 1). Such observations regarding the complexity of syntactic trees have also been fruitful for research on agrammatic language production, indicating a potential common computational substrate for the two processes.

A computational model along these lines (Clark 2009 – see Figure 2) is proposed as an explanation of the performance of a sample of aphasic individuals on twelve sentence structures, as reported in the literature (Caplan et al. 1996). This approach is consistent with a resource reduction approach, and makes use of a component of random noise, such that the model sometimes produces accurate output even when ‘lesioned.’ The model is a modification of freely available software that accompanies an introductory computational semantics textbook (Blackburn and Bos 2006). The modifications include (i) extension of the grammar to include sentences relevant to the study of aphasia, and (ii) incorporation of a variable representing aphasia severity. This severity variable is used to compute the probability of successfully parsing any given node in the tree by the formula
where \( h \) represents the height of the node in the syntactic tree, \( s \) represents the aphasia severity coefficient, and \( p \) represents the percent chance of successfully parsing the node (i.e., including it in the phrase structure representation). At each step in the parse, a random number between zero and 100 is generated and compared to the value \( p \). The parse moves forward only if the step is grammatically legal and the random number is less than \( p \). Thus, constituents that are lower in the syntactic tree are more likely to be parsed and semantically interpreted than constituents higher in the tree. The model generates output in the form of sentences from first-order logic, assembled via expressions from lambda calculus.

There is an additional stipulation that was inspired by Friederici and Gorrell’s Structural Prominence Hypothesis (SPH, Friederici and Gorrell 1998). These authors point out that aphasic individuals have an increased tendency to assign the thematic role of agent to the highest NP in the syntactic tree. This is implemented in the model as a heuristic method for deriving the model’s “behavior” (i.e., a decision of how it would perform in an enactment task) based on the formal logic strings it produces. Specifically, when a transitive verb interpretation occurs with only one argument, the argument is assigned the thematic role of patient. This is, essentially, the contrapositive of the SPH, since it nearly always results in the assignment of the patient role to the lowest NP in a tree structure when the model fails to generate a complete parse.

When the model is run 20 times at each of 21 levels of aphasia severity (setting \( s \) to the values 0–20), its cumulative performance is strongly correlated with that of aphasic patients on the same structures (\( r = 0.85, 72\% \) of the variance). The model does not directly address the question of whether the deficit of agrammatism is primarily syntactic or involves the mapping from syntactic representations to semantic ones, and the effect of number of propositions is dealt with only implicitly.

**Conclusion**

Current evidence points to three avenues by which our understanding of syntax in aphasia – and thus our understanding of language in the brain – may be advanced. The first is
to focus on certain findings from psycholinguistic studies of normal subjects. The example most relevant to this review is the finding that heuristic processes, which may be semantically driven, appear to play an important role in normal language processing (Ferreira and Patson 2007; van Herten et al. 2006). The nature and neural basis for such heuristic processes should receive more attention.

The second important consideration is to create models of agrammatic comprehension that generate explicit semantic representations from syntactic structure. It is possible that much of the variation in patterns of agrammatism can be explained by taking into account compositional semantics (and its reliance on hierarchical structure), along with heuristic mechanisms. Faulty interpretive mechanisms, rather than parsing mechanisms, may underlie the phenomena observed in agrammatic comprehension (Linebarger et al. 1983). Therefore, falsifiable models that make these processes more explicit will aid in dissociating the contributions of each process to the empirical observations. However, identification of a plausible representation for semantic structures is problematic. One approach to characterizing the semantics of words is to classify them according to their co-occurrences with other words (see, for example, Landauer and Dumais 1997). However, this approach does not offer an unambiguous method for the composition of semantic structures associated with sentences. In addition, semantic representations derived from word co-occurrences are sometimes insufficient for explaining the behavior of comprehension.

Fig 2. A parse of the active sentence ‘A man chases a dog’ as described in Clark (2009). Each node in the syntactic tree contains (1) an interpretation expressed in first-order logic and lambda calculus, as described in Blackburn and Bos (2006), (2) a syntactic constituent label, (3) a height, which equals the number of steps from the node to the most distant of its constituent words, and (4) a probability (p), determined by the equation 100−h·s, where h is the height of the node and s (representing aphasia severity) is set to 3. The cumulative probability of correctly producing the entire tree is equal to the product of all the probabilities for all the nodes (approximately 80%). Det = determiner, N = noun, V = verb, NP = noun phrase, VP = verb phrase, S = sentence, ∃ = ‘there exists’ (from first-order logic), @ signifies the application of a lambda expression to its argument. Lambda calculus is a deceptively simple computational system in which a variable bound by a lambda operator (λ) can be replaced by any argument. For example, application of the expression (λn. n × n) to any number yields the square of the number: (λn. n × n)@2 = 2 × 2 = 4.
of human subjects in settings that require consideration of the perceptual knowledge of objects (Glenberg and Robertson 2000). This observation supports the contention that symbols are grounded in perceptual experience (Barsalou 1999). Future work in aphasiology should consider the degree to which semantic structures rest on embodied cognition (see Mahon and Caramazza (2008) for a more nuanced view).

The third consideration for advancing our understanding of sentence comprehension pertains to the ‘resource’ that appears to be reduced in the setting of brain damage. While current evidence supports this conjecture, there is little consensus regarding what the resource actually is, although a reasonable hypothesis is that it is some form of working memory (Caplan and Waters 1999; Haarmann et al. 1997). A great deal of effort has already been applied to using neuroscientific methods as a means of anchoring psychological observations to more physically measurable phenomena. These methods include structural and functional brain imaging, transcranial magnetic stimulation, electro- and magnetoencephalography, and multi-cellular recordings in behaving animals. From the standpoint of disturbed language comprehension, two fruitful avenues for investigation would be better neural characterization of (i) the semantic representations onto which words and sentences are mapped, and (ii) the events underlying sentence parsing and interpretation. The first of these challenges might provide necessary scaffolding for the second, i.e., the mapping from sound to meaning might be more transparent if we have a realistic model of the brain’s representation of meaning. Better understanding of the sentence processing resource that is reduced by brain damage should be present, at least implicitly, in any theory that answers these challenges.

Short Biography

David Clark’s research blends cognitive neuroscience with clinical neurology. He was drawn into neurology by an interest in aphasia and through this has pursued a more comprehensive understanding of language, linguistics, and computation. Current projects include a study relating event-related magnetic fields to brain structure and a comparison of semantic memory measures to blood flow measures for predicting functional decline in patients with memory disorders. Before coming to the University of Alabama at Birmingham and the Birmingham VA Medical Center, Clark undertook a behavioral neurology fellowship at the VA Greater Los Angeles and UCLA. He was trained in neurology at Wake Forest University, in Winston-Salem, North Carolina, USA.

Note

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