Attention and empirical studies of grammar

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Abstract

How is the generation of a grammatical sentence implemented by the human brain? A starting place for such an inquiry lies in linguistic theory. Unfortunately, linguistic theories illuminate only abstract knowledge representations and do not indicate how these representations interact with cognitive architecture to produce discourse. We examine tightly constrained empirical methods to study how grammar interacts with one part of the cognitive architecture, namely attention. Finally, we show that understanding attention as a neural network can link grammatical choice to underlying brain systems. Overall, our commentary supports a multilevel empirical approach that clarifies and expands the connections between cognitive science and linguistics thus advancing the interdisciplinary agenda outlined by Jackendoff.

1. Introduction

In his *Aspects* (Chomsky 1965: 3) Chomsky argues that his ideal speaker-listener must be "unaffected by such grammatically irrelevant conditions as memory limitations, distractions, shifts of attention and interest …" This view underlies the common distinction made in linguistics between competence and performance models of language processing.

Generativism is content to develop competence models in isolation from the basic psychological and neurological systems, i.e., memory and attention. Since the early writings of Chomsky, factors like memory limitations and shifts of attention have been consigned to performance, something with which a theory of competence should not be concerned.

In his new book, Jackendoff suggests a dramatically updated version of generative theory. First, he emphasizes the importance of studies that inquire into

The Linguistic Review 22 (2005), 347–364 0167–6318/05/022-0347

major aspects of performance, such as, sentence production and comprehension. Second, Jackendoff refuses to conform to a clear-cut border between competence and performance: although continuing to maintain the competence-performance opposition, he seeks a better integration of performance factors into competence theory. This permits a *soft* distinction between the two allowing for performance theories to provide insight into our understanding of grammatical competence.

In this article we attempt to advance the general goals outlined by Jackendoff by reviewing how the progress that has taken place in cognitive neuroscience during the past several years can advance a functional linguistics which puts linguistic competence upon a foundation of cognitive and neural mechanisms. In Section 2 (Linguistic Theory) we map grammar onto knowledge representations (see Figure 1). We argue that in order to function, knowledge representations must work in conjunction with the cognitive architecture in order to produce language output. In Section 3 (Attention and Grammar of Discourse), we show how the choice of a grammatical device in the narrative can depend upon a portion of the cognitive architecture, namely attention. In the final section (Attentional Networks), we discuss how attention, as a feature of the cognitive architecture, can be illuminated by a further understanding of how it develops under the influence of genes and experience. In the concluding section we argue that our findings with respect to the influence of attention on grammar may be generalized to advance the links between linguistics and cognitive science.

2. Linguistic theory

Linguistic theory makes its best contribution to cognitive science when its theoretical framework and empirical findings capture thoroughly the extensive variation found in human languages and language use, and when its efforts to do so are constrained by an understanding of the architecture and associated processing systems through which language is embodied in human cognition.

Chomsky (1988) articulates four key problems for linguistics and linguistic theory (see Figure 1): (1) knowledge of the grammar (KNOWLEDGE REPRESENTATIONS); (2) acquisition of that knowledge (ACQUISITION); (3) use of that knowledge (USE), and, most recently, (4) how that knowledge is tied to the brain that implements it (ARCHITECTURE). Another problem, not so explicitly articulated, though also central, is the discovery of what it is about human language that makes it so uniquely human, something no other species remotely shares with us (Hauser et al. 2002).

Of these four central problems, two have dominated research within the generative tradition – both the continuing tradition following closely the work of

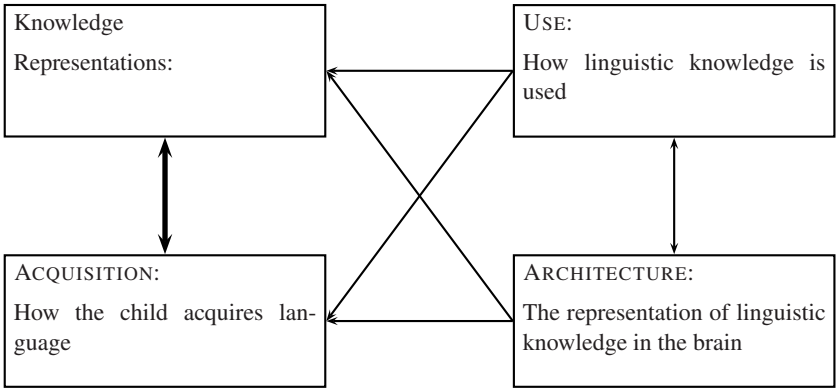

Figure 1. Four central questions of linguistic theory

Chomsky and related scholars and derivative approaches: (1) representations of the knowledge of the grammar, especially syntax, focused on the problem of constraining the notion of a possible sentence; and (2) initial acquisition of those representations by the child, with some attention to the interaction of these two problems.

Two principal commitments accompany these basic problems. The first commitment is to the construction of a structuralist theory wherein the essential character of human language is imagined to be captured primarily, if not exclusively, as constraints on the configuration of abstract structural units of one kind or another. The second commitment is to method, and there is a fundamental method deployed in linguistic research: introspection on the well-formedness of utterances. Grammaticality judgments remain the principal methodological tool, though other methods are occasionally entertained, mostly through reference to work outside linguistics itself.

The union of the two principal questions (KNOWLEDGE REPRESENTATIONS and ACQUISITION) with commitments to structuralist theory and introspective method invites, at least in practice, the creation of increasingly abstract theory divorced from the messy data of human experience. Variation is treated generally as noise in the system, largely ignored as the theory is constructed, or, explained away as artefacts of processes external to language, assigned to irrelevance as part of performance.

It is worthwhile to recall what aspects of linguistic behaviour are attributed to performance by traditional generative theory. These things are "... such grammatically irrelevant conditions as memory limitations, distractions, shifts of

attention and interest, and errors …"(Chomsky 1965: 3). In classical Chomskian view these factors should not concern a theory of linguistic competence, as they are too heterogeneous.

We cannot subscribe to the view that these factors are not necessary to analyze if one seeks to establish a viable theory of language. Language exists and develops largely in the performance mode. The theory of linguistic competence either needs to seek to account for performance variation or try to rule performance factors out – it cannot just discard them as unnecessary.

On the other hand there exists a strong psycholinguistic tradition of studying regularities in grammar by analyzing effects of memory limitations on the choice of grammatical forms (i.e., Sanford and Garrod 1981, 1994; van Dijk and Kintsch 1983; Just and Carpenter 1992), contributions of attention to the organization of speech grammar (see Section 2), and speech errors and repairs (i.e., Garrett 1975; Dell 1986; Levelt 1989). Our general view can be positioned within this tradition.

Any abstract theory of domain-specific knowledge imposes limitations that can be appreciated through an example. Consider the case of a dog catching a Frisbee thrown by its owner. The Frisbee does not travel in a straight line but follows an arcing path through the air, and the dog typically also runs along a curving path, timing its run and path to readily catch the disk. We could ask about how the dog does this, what the knowledge representations of the paths of the Frisbee and the dog are like for the dog, and what the cognitive systems are like that permit the dog to succeed regularly in coordinating its locomotion with the flight path. One kind of theory, perfectly adequate in a descriptive sense, would look at the mathematics of the flight path of the Frisbee and assert that this mathematics represents the knowledge the dog must have of the flight path of the Frisbee. Such a theory does not, of course, claim that the actual knowledge in the mind of the dog is in fact the same kind of representation that one uses for the mathematical model, but it does ask that we explore the dog's abilities *as if* its knowledge representations were of that kind. And the corresponding research agenda one might develop to investigate how the dog catches the Frisbee will be constrained by this theory.

First, it constrains the way in which research problems are conceptualized to begin with, requiring them to conform to the representational imaginings of the theory, even though the theory may well grant that it does not approximate well the pertinent knowledge representations in the cognizer, the dog in this example. Second, it constrains in a corresponding fashion the invention and adaptation of methods for empirical study since what you can see empirically is systematically related to what you can conceptualize theoretically. An alternative theory, one in which the nature of knowledge representations approximates or mimics what we have learned about knowledge representations in cognition more generally, is in our view to be preferred (even with accompa-

nying empirical limitations) to one that lacks coherent connection to the details of architecture and the nature of accompanying processing systems.

This view leads to revision of the traditional competence-performance distinction. In its original formulation, the commitment to competence permitted one to see, for example, that embedding of clauses with verbs like *believe* is infinitely recursive, despite limitations in memory that make more than three or four embeddings unlikely in actual performance. In this case limitations in memory are appropriately set aside as not directly relevant to the grammar of English. Nonetheless, not all matters involving cognitive operations of memory or attention sit so readily outside the grammar. As we discuss in more detail below, the cognitive conditions associated with the assignment of referents to a subject in English (reflected in its voice system), in particular attention, appear to constrain directly the use of linguistic structures during language production. Such constraints, grounded in central cognitive and neurological systems, capture another type of linguistic competence, one in which the mapping between linguistic form and semantic or conceptual representation is tied to the nature of the cognitive systems defined by fundamental human cognitive architecture.

In the end, the noise, more properly the variation, does not go away; it remains to be explained. Among linguists, accounting for the "noise" of linguistic performance is tied in increasingly interesting and compelling ways to the other central questions for the field: USE and ARCHITECTURE.

There is, of course, a great deal of work on acquisition framed in terms of its constraint by ideas about the nature of knowledge representations for language, the so-called logical problem of language acquisition. But there is also a considerable body of work that examines the social and cognitive processes that implement acquisition, and such work pursues the details of dynamic change. This agenda of research on acquisition defined by scholars such as Slobin, Tomasello, Bates and MacWhinney, Bowerman, and others aims at understanding how language emerges from the details of social interaction and cognitive development.

Being an important source of variation, language use permits regular mappings of the semantic and pragmatic details of a grammar onto its system of forms. In general, languages offer structurally distinct ways of conveying essentially identical messages: variation in referential form, variation in voice and related systems, variation in constituent orders, variation in complementation and its relation to the packaging of events, and even individual morphemes whose use remains elusive (Japanese *wa*, for instance). Such problems, defined by scholars like, Givón, Chafe, Bates and MacWhinney, Kintsch and van Dijk, Langacker, Talmy, and Dik, have stimulated some linguists to seek the cognitive bases for the semantic and pragmatic notions whose prior theoretical status was grounded in structuralist theory and introspective methodology.

Language variation poses considerable challenges to linguistic theory, especially as one brings cognition into the descriptive and explanatory game. Linguistic *theory* has tended to downplay the issues related to language use, both in their own right and in their potential to contribute to a comprehensive theory of human language behaviour. Within the mainstream, variation is treated as mere performance and not part of the central endeavour, something to be left to psychology or sociology to deal with.

Thus, while the classic competence/performance distinction is intended to constrain the enterprise of developing linguistic theory, it has in fact limited it. In parallel with its commitment to abstract representations of linguistic knowledge, the conventional idea of competence and performance embraces an overly simplistic notion of the target of investigation, the nature of the grammar of the speaker. The distinction is initially helpful, in that it directs the focus of research to the ability of the speaker to create well-formed utterances without undue attention to certain vagaries of production – slips of the tongue, forgetting, and such, though these need not be seen as random and irrelevant to understanding human language. However, it also invites one to conclude mistakenly that the grammar of a speaker is somehow a relatively fixed system of constitutive rules in which all variation arises out of one or another kind of (mere) performance failure. It invites the nativist argument, drawn straight out of Plato's *Meno*, that since the end product is fixed and complete, the system must already be essentially in place *a priori* and that language input in the social environment plays a relatively minor role in acquisition since that input is limited and "flawed". It also permits the trivialization of use and concomitant issues of language processing, relegating those issues to the "parser", lower level systems that manage the details of implementation of the abstract grammar.

In the end, it *is* the speaker's competence that must be described, but the details of that competence must go beyond those associated with the idea of an ideal speaker-hearer without limitations of memory and such. Human grammars operate with components that reflect precisely those cognitive processes tied to mapping non-linguistic representations into language. Voice systems – active vs. passive in English, but more complex systems in other languages (Tagalog, for example) – likely reflect the interaction of processes of attention with syntactic form, selecting some information as more salient or relevant to some task at hand. The selection of referential form – pronominal vs. nominal NPs, and these latter sub-categorized by the complexity of the modifications of the head – likely reflects something of the management of the elements in memory by the speaker and hearer. Systems without the internal need for directing of attention or sustaining or renewing a mental representation – for example, any typical desktop computer – do not need languages with voice or fine-grained systems of nominal reference. These complexities arise from the

characteristics of human cognition, and language does not shunt these matters off to performance nor should linguistic theory.

In the end, the aspects of language related to its PERFORMANCE require dealing with the results of language USE - variation. While the principal theoretical structures and methods that linguists use in dealing with variation include structuralist categories and argumentation, the study of variation in USE requires additional exploratory methods. These methods, whether drawn from chronometric and experimental protocols of psychology or from the potential of neuroimaging, will re-shape linguistic theory.

In the next section, we will discuss how linguistic performance may experience systematic constraints imposed by cognitive architecture. More specifically, we will review experimental evidence for the idea that a part of the architecture (attentional system) may influence the language grammar in course of speech production and comprehension.

3. Attention and the grammar of discourse

When people talk they need to properly organize semantic and syntactic structure of their narratives in order to facilitate communication. A part of this process is being able to identify, track, and bind concepts in the discourse. A significant body of experimental work suggests that mechanisms of attentional control are actively involved in various aspects of human discourse.

Traditional definitions of attention have been subjective, for example William James defined attention as "taking possession by the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought" (James 1890: 403–404). More recently it has become possible to examine attention in terms of specific mechanisms that maintain the alert state, orient to sensory events, and mediate between conflicting responses (Posner and Dehaene 1994). This allows identification of the neural networks that underlie attention (see Section 4).

Psycholinguistic research connects at least these three areas of language processing to attention:

(A) ordering of constituents in discourse production;
(B) disambiguation of syntactic structure in comprehension of discourse;
(C) choice of the expression to refer to the entities previously mentioned in discourse.

Readers interested in the research in (B) are referred to recent reviews (Tanenhaus and Trueswell 2004; Tanenhaus et al. 2004; Altman and Kamide 2004), while summary of the research in (C) may be found in (Stevenson 1996; Garnham 1987; 1999; Myachykov and Posner 2005). In the remaining part of this section we will concentrate on the evidence for non-arbitrary ordering of con-

stituents in the sentence as a result of unequal allocation of attention toward the entities the sentence concerns.

The idea that assignment of syntactic roles in a clause may be due to the salience of the entities being described and, therefore, to the speaker's attentional focus has a long tradition. In some early experiments, researchers primed either agent or patient by manipulating their salience, thus eliciting voice alternations in subsequent sentence-picture verification or sentence recall tasks. For example, Johnson-Laird (1968) showed that subjects preferred large and more salient referent points to small ones in verifying pictures and their possible descriptions. Turner and Rommetveit (1968) manipulated focus of attention by priming either agent of patient of the picture during the storing and retrieving sentences. They discovered that this manipulation influenced the voice, in which the sentences were recalled. Tannenbaum and Williams (1968) attracted attentional focus to the agent or the patient by presenting subjects with either an agent-laden or patient-laden text. This, respectively, facilitated active or passive voice descriptions of a picture, presented afterwards. Olson and Filby (1972) primed subjects' attention by showing a picture of either the agent or the patient of a transitive event before presenting the picture of the event itself. In subsequent sentence-picture verification task, subjects interpreted the pictures and the sentences by starting with an attended protagonist and applying grammatical voice from that perspective.

Reports by R. Tomlin (1995, 1997) suggested arguably the strongest support for the idea that orienting of attention influences syntactic structure in speech production. Tomlin designed a computer animation program called the "Fish Film" (Figure 2). Subjects viewed and described an unfolding engagement of the two fish in real time. In each trial one of the two fish was visually cued (arrow in Figure 2). The cue attracted the subjects' attention (Posner 1980). The critical part of each trial was eating of one of the fish by the other (dynamic event). The descriptions of the dynamic event became the target utterances for further analysis.

English speakers varied assignment of the syntactic subject depending on the visual cue (Tomlin 1995). When the patient fish was cued and was then eaten by the agent fish the subjects said, *"the dark fish was eaten by the light fish"*. When the agent fish was cued the same event was described as *"the light fish ate the dark fish"*. Attention to the cue influenced the choice of the syntactic subject of the sentence and the choice of grammatical voice that mapped onto this assignment.

One recent study (Nappa et al. in press) further supported this finding. In this study, attention was manipulated covertly: it was captured via a brief presentation of black target stimulus against a white background immediately prior to the scene viewing. Eye movements were tracked as indication of the success of attentional cueing (Fischer 1998). Two types of scenes were described: (1) ones

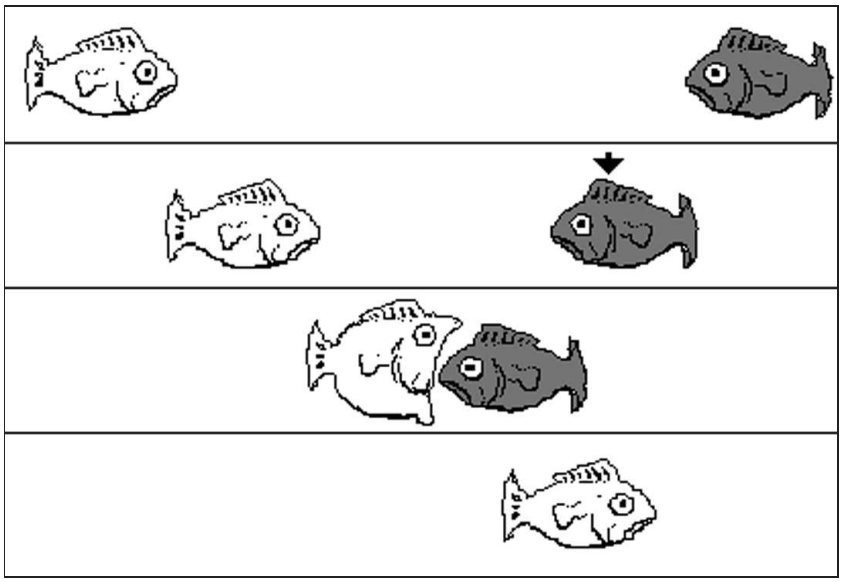

Figure 2. The fish film

eliciting a *conjoined noun phrase* (CNP) and (2) ones requiring use of a *perspective verb* (i.e., give/receive). Analysis of collected utterances suggested that the primed character was likely (1) to appear first in CNP utterances and (2) to be a subject of Perspective verb utterances. The former result provides support to the thesis that the order of mentioning may influence consecutive choice of grammatical subject. The latter supports the idea that the allocation of attention influences assignment of the grammatical subject.

Eye movements and fixations have also been observed to precede word production (Meyer et al. 1998; Levelt and Meyer 2000; van der Muelen et al. 2001). It was also observed that name-related gazes reflect locus of attention but not semantic information contained in the scene (Griffin 2004). These results provide important support for the thesis that attention is actively employed in lexical access as well as in the organization of syntactic structure.

Manipulations of attention were also used to study the assignment of the grammatical subject and the choice of specific lexical item in production and verification of *locatives*. For example, Clark and Chase (1972) presented subjects with a picture of an asterisk either above or below a plus. The sentence accompanying the picture might, for instance, read *"star is below plus"*. In Experiment 3, subjects were directly instructed to attend to either (1) whole

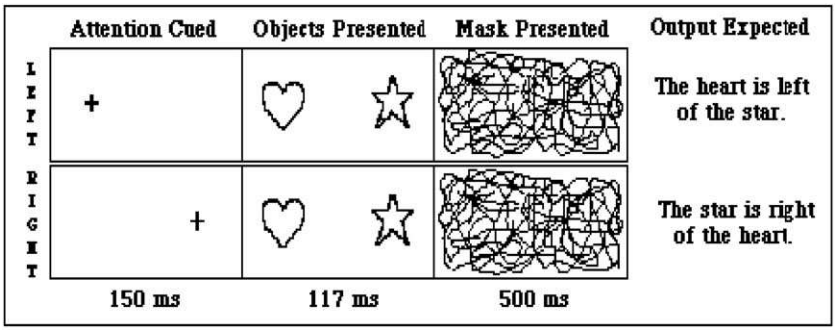

Figure 3. Example of the experimental sequence from Forrest (1997)

picture, or (2) the top of it, or (3) the bottom before comparing the sentences to their pictorial counterparts. The results supported the idea that subjects anchored their attention depending on *above* or *below* indices: directing attention to either above or below facilitated verification of the relevant locative descriptions.

L. Forrest (1997) used a similar approach in a production study. She manipulated subjects' attention to one of quadrants of the display with the help of a visual cue, then presented visual array of objects, which was followed by a mask, and collected the descriptions of the observed scene. The location of the cue influenced the resulting narrative in a fashion similar to Tomlin's (see Figure 3).

The reports discussed so far seem to have demonstrated that the choice of syntactic subject position might result from the direction of attention. However, one of the criticisms to such accounts is their reliance on English syntax, which is known for its relative rigidity: it suggests binary variation of word order based on the alternation between active and passive grammatical voice. Languages with more combinatorial freedom might not demonstrate a direct correlation between assignment of the syntactic subject and allocation of attention. It may also be that interaction between a visual cueing scheme and the choice of syntactic pattern might be revealed differently in languages other than English.

In order to test latter assumptions, the Fish Film protocol was applied to the analysis of Russian utterances (Myachykov and Tomlin in preparation). Russian is characterized by a flexible ordering of constituents with a default higher-frequency pattern – SVO. As in other flexible word order languages, the first position in a Russian sentence does not necessarily imply that this position is assigned to the grammatical subject. Such a grammar permits, at least in theory, other possible combinations, such as OVS, OSV, or even verb-

initial sequences like VSO. Functional theories of Russian word order repeatedly suggested that the clause-level theme (the topical, background, or presupposed information) should enter the sentence first. The rheme (the comment, foreground, or new information) should follow the theme (i.e., Adamec 1966; Krylova and Khavronina 1988; King 1995).

The association between theme and initial slot in the sentence provides a solid theoretical prediction for Fish Film experiment: Russian word order should map onto the cueing scheme so that the trials, in which the cued element is the agent should be covered by agent-first utterances (SVO, SOV) while the patient-cued trials should be described by the utterances with patient in the initial position (OVS, passive voice).

In conflict with this prediction, native Russian speakers preferred agent-first patterns (predominantly SVO) to all other available sequences regardless of the cueing. This preference, however, entailed some notable implications: (1) in the utterances that started with the agent regardless of the fact that the patient fish was cued there was a hidden attentional switch: the speech on-set latencies (SOL) were significantly longer (ca. 202 msec) in the agent-first utterances that were elicited when the cued element was the patient fish; (2) the latter group of utterances was characterized by a significantly higher speech error rate: subjects experienced difficulties defining which case marker they needed to attach in order to produce the correct sentence.

These results show that underlying the grammatical choice there is an attentional component that works similarly irrespective of the language involved. The surface utterances differ in syntactic form between languages, but the mechanism of attention works very similarly. In English attention stays on the cued item and the syntax varies between active and passive forms, but in Russian, presumably because use of one word order is more frequent and because of necessity to choose a proper case marker, which increases operational load, there is a hidden switch to maintain attention the same over syntax.

The *patterns of interaction* between attention and the language device in the two languages are nevertheless different. The correspondence between the grammatical subject and the attentionally detected entity in English is established consistently while Russian speakers choose to stick to an agent-driven word order. The difference in our view is in the ways attention interfaces with the syntactic structure of the narrative in the two languages. The interface for English might be *attend____then____assign subject*. We expected to see the principle *attend___then___assign theme* at work in Russian. This principle should have resulted in the subject-first/object-first choice of word order depending on which of the referents, agent or patient, was cued. However, the way attention interacts with language in Russian does not permit this correspondence: the subjects choose to switch their attention from the cued to the non-cued referent in order to arrive at the preferred word order. Hence, syntac-

tic convenience seems to overrule attention: despite cueing of other thematic roles in the sentence, the subject in Russian sentence is preferably placed first. This shows that a frequent usage of a particular pattern can override attention cueing. That in effect suggests that formal properties of language can be in conflict with cognitive processing.

The difference in attention-language interface observed in the two languages is well accounted for in Slobin's *thinking for speaking* theory (Slobin 1987). In this view, the process of thinking for speaking involves choosing specific characteristics of the event that (a) fit its conceptualization and (b) are readily *encodable* in the language (Slobin 1987: 435). A more codable expression is more accessible in psycholinguistic terms. Much in accordance with our view, thinking for speaking assumes a non-arbitrary pattern of interaction between thought and language triggered by the linguistic code. In the context of Russian language, and in on-line format, preference in word order triggers a shift of attention from one referent to the other in order to facilitate speech.

Although these conclusions are by no means final, and we admit that our evidence is limited to a small number of studies, these data demonstrate how patterns automated in the language may define interface between the cognitive system and the language device.

The experimental findings we examined in Section 3 converge in their support of the idea that linguistic competence and performance are intrinsically interrelated and interdependent forms of language existence. We demonstrated how one part of the cognitive architecture, namely attention, interacts with grammar. This interaction illustrates how the cognitive system imposes regular constraints on language. Similarly, the language grammar may reciprocate this influence. The effects of the latter interaction are difficult to trace in off-line linguistic data, as these effects probably do not continue outside real time speech format. Analysis of on-line speech in some languages (Russian) made it possible to demonstrate how automated grammatical patterns may trigger specific changes in the ways cognitive system (attention) functions. This provides important insight into the internal organization of the interfaces between different languages and the cognitive architecture. The next section will take the view we advocate here into the nearest future: we will be analyzing recent evidence from the fields of neuroscience and psychogenomics that connects brain networks related to attention and language processing to the genes contributing to their development and functioning.

4. Developing brain networks

Of what use is it to know that attention is involved in comprehension and production of discourse? As long as attention was an entirely subjective concept it

was probably not particularly useful for linguistics to posit "attention" as important in the development of syntax. However, the orienting network discussed in the last section is now known to involve several parietal sites (Corbetta and Shulman 2002) and to be influenced by cholinergic input from frontal areas (Davidson and Marrocco 2002). These findings help link the neural networks involved in language, which are known from imaging studies, to those driving the attentional influences on grammar discussed in Section 3.

Because both humans and alert monkeys have similar attentional orienting systems, it is possible to compare cellular recordings from indwelling electrodes in monkeys with scalp recordings from humans to obtain the time course for the activation of these anatomical areas (Abdullaev and Posner 1998; Corbetta and Shulman 2002). These studies provide the opportunity to validate the time course for operations in eye movement studies with time for internal operations in the brain. For example, eye movement studies of reading suggest that fixation times for skilled readers on a particular word are about 275 milliseconds. Because the length and direction of the saccade can reflect semantic information obtained from that word, there is a limited time to derive semantics from the input word. Evidence from brain imaging suggests that frontal areas involved in attention to semantics can be activated within about 150 msec. after input, time enough to influence the saccade length (Posner et al. 1999).

It is also possible to go from an understanding of attentional networks to some knowledge of how genes influence their development. The method of doing this may be instructive for understanding critical aspects of determining how genes influence language. While there is strong evidence of common networks that underlie cognitive processes, there are also differences among individuals. These differences are likely to reflect both genes and experience. The rapid development of fMRI methods has begun to provide a basis for understanding differences among individual brains both anatomically and in terms of functional activations, these differences are to be expected because people are not identical in their thoughts, feelings or behaviors.

It is possible to begin the process of finding the genes responsible for the development of particular networks by examining phenotypic differences in people. In the case of attention, we developed the Attention Network Test as a measure of the efficiency of each of the attention networks (Fan et al. 2002). It is then possible to obtain rough guides to the genetic involvement of the task by running twin studies (Fan et al. 2001). The executive attention network, known to involve the anterior cingulate and other frontal areas, was shown to have a high heritability; that is, there was a much higher correlation among identical twins than fraternal twins, thus suggesting a role for genes. Since the areas of the brain involved in this network are primarily modulated by dopamine, we looked for variability among people in several dopaminergic genes. We found several polymorphisms (differences in genes) that are related specifically to

performance in the executive network (Fossella et al. 2002). When some of our subjects were scanned during administration of the Attention Network Test, we found the expected effects of genetic differences between subjects in the anterior cingulate, which is one of the primary nodes of the executive network (Fan et al. 2003).

How might this approach be used to illuminate questions of language? The study of genes related to language has most often been through examination of disorders (Lai et al. 2001; Bishop 2002). These may give insight into the evolution of language. However, other methods may be useful as well. Chomsky has proposed an innate language device central to the unique aspects of human grammar namely recursion (Hauser et al. 2002). In his book, Jackendoff tries to develop an evolutionary account that would allow natural selection to produce such a device. In turn, we propose a complementary approach based on our attention findings that could lead to an evolutionary account of normal variation in language use at the molecular level.

Suppose one believes at the core of grammar (e.g., recursion) there is an innate language device specified in the human genome. Is it possible that performance studies could help us understand this device? An important step is to develop a reliable test of recursion that can be studied systematically among a large set of people. Since no single test might capture all of the critical properties of recursion, a battery of tests might be needed. Studying a set of people with such a test battery could then produce reliable individual differences in carrying out recursion even though all the people would have knowledge of the grammar of their language. These individuals would be genotyped for a number of genes that might be related to grammatical skill.

Which genes would be used? Currently, many groups have been examining candidate genes in abnormalities of language (Liu et al. 2001; Bishop 2002; Enard et al. 2002) and in related disorders such as dyslexia (Grigorenko 2003). These studies provide leads as to what genes may be involved. Of course, as in all empirical efforts, there is no guarantee that any single gene or combination of genes will be found to predict individual differences in recursion.

However, it is clear from the plan we outlined above that there is at least a possible empirical agenda to study in detail the nature of the innate linguistic device underlying grammar. This agenda has been successful in finding specific genes that influence complex networks in attention and memory (see Goldberg and Weinberger 2004). Success in these human studies could allow one to trace some of the elements of recursion in rodents and primates thus providing the basis for a comparative study of the elements of syntax at the molecular level.

5. Conclusions

In our article we have sought to advance the agenda proposed by Jackendoff by illustrating how one cognitive system, attention, interacts with language. We discussed important empirical findings, which are based upon combining empirical methods from cognitive psychology, such as reaction time and eye movements, along with neuroimaging and genetics research that is developing in cognitive neuroscience. These methods seem to allow an opportunity to examine the mechanisms of language comprehension and production at cognitive, neural and genetic levels and thus advance the productive interdisciplinary approach. In general, we tried to emphasize that the key to understanding how the mind works can be found in studying language, especially in studying performance tasks of language.

Jackendoff proposed to treat competence and performance as modes of language functioning with a much larger degree of permeability than traditionally permitted in generative theory. This move is admirable as it allows generativism to adapt the idea of regular reciprocal interactions between knowledge of *language rules* (competence) and regular instances of *language use* (performance). However, we remind the reader that this claim is a new contribution to the generative theory while psycholinguistics has been long producing evidence for this idea. In our theoretical claims, we subscribed to the general proposal that linguistic competence and performance are intrinsically interrelated and interdependent forms of language existence. This, in effect, entails that the cognitive architecture regularly interacts with knowledge representations in the production of discourse.

We reviewed some experimental evidence that converge in their support of this idea. We demonstrated how one part of the cognitive architecture, namely attention interacts with grammar. This interaction illustrates how the cognitive system imposes regular constraints on language. Similarly, the language grammar may reciprocate this influence. The effects of the latter interaction are difficult to trace in off-line linguistic data, as these effects probably do not continue outside real time speech format. Analysis of on-line speech in some languages (Russian) made it possible to demonstrate how automated grammatical patterns may trigger specific changes in the ways cognitive system (attention) functions. This provides important insight into internal organization of the interfaces between different languages and the cognitive architecture.

In the final section we reviewed an ambitious agenda of trying to understand attentional influence on language at the level of development of brain networks. Of course we do not know the outcome of such studies, but it seems entirely possible that they would yield detailed information about the innate language learning device that would illuminate questions about its anatomy, development and why individuals differ in their ability to acquire language. If

so, even those holding most strongly to the idea that language is unique might embrace an empirical approach to unraveling its underlying substrate. Based on studies of attention and memory, we propose a strategy for seeing which genes influence the development of grammar.

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