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The Extended Argument Dependency Model: A Neurocognitive Approach to Sentence Comprehension Across Languages

Ina Bornkessel
Max Planck Institute for Human Cognitive and Brain Sciences

Matthias Schlesewsky
Philipps University Marburg

Real-time language comprehension is a principal cognitive ability and thereby relates to central properties of the human cognitive architecture. Yet how do the presumably universal cognitive and neural substrates of language processing relate to the astounding diversity of human languages (over 5,000)? The authors present a neurocognitive model of online comprehension, the extended argument dependency model (eADM), that accounts for cross-linguistic unity and diversity in the processing of core constituents (verbs and arguments). The eADM postulates that core constituent processing proceeds in three hierarchically organized phases: (1) constituent structure building without relational interpretation, (2) argument role assignment via a restricted set of cross-linguistically motivated information types (e.g., case, animacy), and (3) completion of argument interpretation using information from further domains (e.g., discourse context, plausibility). This basic architecture is assumed to be universal, with cross-linguistic variation deriving primarily from the information types applied in Phase 2 of comprehension. This conception can derive the appearance of similar neurophysiological and neuroanatomical processing correlates in seemingly disparate structures in different languages and, conversely, of cross-linguistic differences in the processing of similar sentence structures.

Keywords: psycholinguistics, language comprehension, extended argument dependency model, neurotypology, neurocognition

In the investigation of human cognitive abilities, language has always played a primary role. Nonetheless, many unknowns remain with respect to the organization of this highly complex and uniquely human skill. In particular, very little is known as yet about how the astounding diversity of human languages can be reconciled with the presumably shared cognitive and neural bases in which these individual languages must be grounded. Thus, although a rich psycholinguistic tradition has led to considerable advances in the modeling of language processing mechanisms in English since the 1960s, a systematic extension of these empirical investigations to other languages has only begun much more recently. In view of this growing body of cross-linguistic data, it now appears of primary importance to formulate new classes of psycholinguistic models that explicitly address the cross-linguistic dimension.

The importance of cross-linguistic factors in modeling language processing is highlighted by the emergence of seemingly puzzling cross-linguistic differences in recent findings on the neurocognitive bases of language comprehension. For example, there are apparent inconsistencies with regard to the involvement of Broca's region (i.e., the pars opercularis and triangularis of the left inferior frontal gyrus; BA 44/45) in the comprehension of word order variations (object-before-subject sentences) across languages. A number of studies examining English have suggested that object-relative clauses, as in *Peter defended the gardener who the butler accused*, can lead to activation increases in Broca's region in comparison with subject-relative clauses, such as *Peter defended the gardener who accused the butler* (e.g., Caplan, Alpert, Waters, & Olivieri, 2000; Constable et al., 2004; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Keller, Carpenter, & Just, 2001; Stromswold, Caplan, Alpert, & Rauch, 1996). By contrast, similar sentence structures in German fail to yield comparable activation patterns (Fiebach, Schlesewsky, Lohmann, von Cramon, & Friederici, 2005; Fiebach, Vos, & Friederici, 2004). Rather, pars opercularis activation has been reliably observed in German sentences involving an entirely distinct type of word order permutation known as *scrambling* (Bornkessel, Zysset, Friederici, von Cramon, & Schlesewsky, 2005; Fiebach, Schlesewsky, Bornkessel, & Friederici, 2004; Grewe et al., 2005; Röder, Stock, Neville, Bien, & Rösler, 2002). The demonstrated involvement of the same neural substrate in seemingly disparate processing operations in different languages, rather than in the processing of overtly comparable structures, poses a striking challenge to the common assumption that processing mechanisms are identical—or at least

Ina Bornkessel, Independent Junior Research Group Neurotypology, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany; Matthias Schlesewsky, Research Group Neurolinguistics, Philipps University Marburg, Marburg, Germany.

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Correspondence concerning this article should be addressed to Ina Bornkessel, Independent Junior Research Group Neurotypology, Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, 04103, Leipzig, Germany. E-mail: bornke@cbs.mpg.de

very similar—across languages (cf., for example, de Vincenzi et al., 2003; Fodor, 1998). Rather, these findings indicate that there may indeed be not only important language-particular differences with respect to comprehension routines and their neural implementation, but also similarities that are not easily derivable from superficial properties.

Psycholinguistic and neurolinguistic research is thus faced with the challenge that adequate cross-linguistic models of comprehension should be able to account for such variability, while also deriving underlying similarities, which are presumably at least partly attributable to common cognitive and neural bases across languages.

Crucially, further findings in the domain of argument processing have indicated that processing differences of the type described above are not only quantitative, but rather may even be qualitative in nature (Coulson, King, & Kutas, 1998; Frisch & Schlesewsky, 2001; Frisch, Schlesewsky, & Wegener, 2005). They thereby appear to defy explanation simply in terms of differences in the relative frequency of occurrence of the critical structures across languages.[1] Moreover, qualitative differences are also an issue within individual languages, as the distinction between different types of word order variations shows. Not only do clause-medial (scrambled) object-before-subject orders engender distinct activation patterns to object relative clauses and object *wh*-questions in neuroimaging studies on German (see above), they also consistently elicit qualitatively different electrophysiological responses (Bornkessel, McElree, Schlesewsky, & Friederici, 2004; Bornkessel, Schlesewsky, & Friederici, 2002b; Friederici & Mecklinger, 1996; Friederici, Steinhauer, Mecklinger, & Meyer, 1998; Frisch, Schlesewsky, Saddy, & Alpermann, 2002; Matzke, Mai, Nager, Rüsseler, & Münte, 2002; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998; Schlesewsky, Bornkessel, & Frisch, 2003). Electrophysiological differences are apparent not only in unambiguous sentences, in which case they are observable at the position of the fronted object itself, but also in locally ambiguous structures requiring a reanalysis toward the object-initial order (for converging behavioral findings, see Bader & Meng, 1999). This data pattern thus leads to the conclusion that object initiality cannot be accounted for by means of any single processing mechanism.

As the positioning of an object before the subject in a simple, two-argument sentence is a very common and basic operation in many of the world's languages, it is surprising that word order phenomena are afforded only very little attention in current models of sentence comprehension. Whereas generally higher processing difficulty for object-initial sentences (across languages) can be derived within several existing models such as Gibson's syntactic prediction locality theory/dependency locality theory (Gibson, 1998, 2000), models of filler-gap dependency (Crocker, 1994; de Vincenzi, 1991; Frazier & Flores d'Arcais, 1989), and nonlexicalist constraint-based accounts (Keller, 2000; Keller & Alexopoulou, 2001), other approaches are either not designed to model word order phenomena by their own account (Lewis & Vasishth, 2005) or encounter difficulties when object-before-subject structures diverge from the English type (e.g., in object-subject-verb vs. subject-object-verb structures; MacDonald, Pearlmutter, & Seidenberg, 1994; Townsend & Bever, 2001; Vosse & Kempen, 2000). However, none of these models is suited to deriving the qualitative differences between object-initial orders in different sentence types both within a language and across languages.

The aim of this article is to introduce a new cross-linguistically oriented, neurocognitive model of incremental language comprehension that is capable of deriving fine-grained distinctions such as those described above. This model, which we refer to as the *extended argument dependency model* (eADM), is primarily concerned with the processing of core relations, that is, the relations holding between sentential arguments and between arguments and verbs. Thus, rather than focusing on complex linguistic phenomena such as modifier attachment or centre embedded structures, the eADM models cross-linguistic processing behaviour in the most basic of utterances: simple sentences (i.e., one-argument, two-argument, or three-argument clauses). As we show below, the relative positioning of subjects and objects is only one of a larger class of phenomena relevant to this issue.

With the eADM, we thus aim to address the following central questions: How does real-time argument interpretation take place from a neurocognitive perspective, and how do the properties drawn upon in this regard depend on the particular language being processed? For example, are properties such as argument position and morphological case equally informative with respect to incremental argument interpretation? Which properties of the comprehension architecture are responsible for deriving processing effects that occur in the absence of verb information, that is, before the verb is encountered in a verb-final structure? Do processing phenomena of this type differ from effects that can be observed when the verb has already been processed? As these major considerations indicate, the basic architecture of the model is constrained by the endeavour to render it applicable to a wide range of languages. In addition, the model is designed to derive neurophysiological and neuroanatomical processing correlates of core constituent processing across languages and how these map onto the behavioral output. In this way, cross-linguistic similarities and differences in neurocognitive processing signatures are viewed as evidence for underlying unity or diversity of the mechanisms under consideration.

In the following, we begin by introducing the architecture of the model before discussing the requirements resulting from a cross-linguistic perspective and presenting converging neurophysiological and neuroanatomical evidence from several languages. Subsequently, we show how cross-linguistic predictions can be derived from the model and illustrate the model's predictive capacity on the basis of selected examples. In the two final sections of the article, we outline the relationship between the model and behavioral findings on language comprehension, and we discuss the relationship between the eADM and other related models of language comprehension.

The Architecture

The complete processing architecture of the eADM, which is a fundamentally extended version of that described in Schlesewsky and Bornkessel (2004), is shown in Figure 1.

[1] More generally, as pointed out by Jurafsky (2003), it remains to be shown how successful probabilistic approaches can be in deriving purely abstract or structural (i.e., nonlexically driven) processing phenomena.

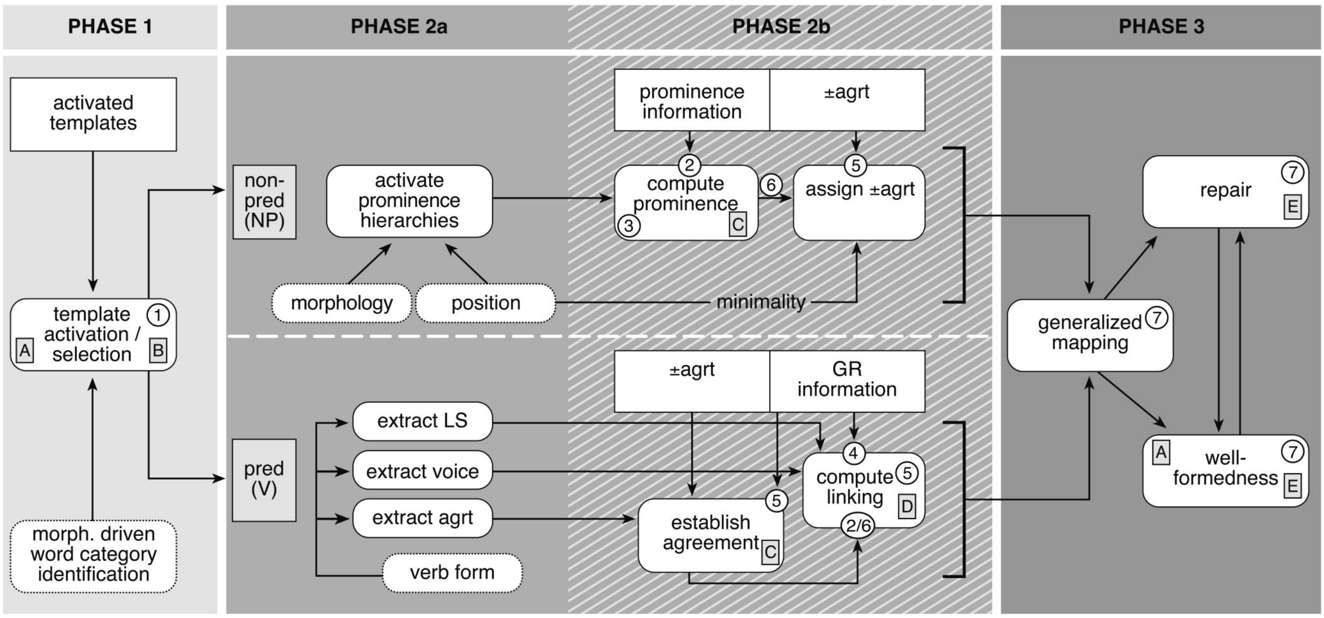

Figure 1. The architecture of the extended argument dependency model. Input information to the current processing stage deriving from previous processing steps (i.e., representations established in response to previous input items) is coded in rectangles. Input information deriving directly from the item currently being processed is coded in rounded boxes with dotted lines. The rounded boxes with solid lines represent the current computational steps in each processing phase. The relationship between the three phases reflects hierarchical dominance. Numbers index ERP correlates of the individual processing steps: 1 = early left anterior negativity; 2 = N400; 3 = scrambling negativity; 4 = early positivity (P345); 5 = left anterior negativity; 6 = P600; 7 = late positivity. Letters index neuroanatomical correlates of individual processing steps: A = deep frontal operculum; B = anterior superior temporal gyrus; C = inferior frontal gyrus, pars opercularis; D = posterior superior temporal sulcus; E = basal ganglia. morph. = morphologically; pred = predicating; LS = logical structure; GR = generalized semantic role.

As indicated above, the eADM is concerned with the processing of core constituents, that is, essentially the verb and the arguments required by it. It does not—in its current formulation—seek to explain processing behaviour pertaining to nonobligatory constituents (e.g., attachment behaviour of relative clauses and prepositional phrases, adverb interpretation), as we follow Frazier and Clifton (1996) in assuming that this is subject to fundamentally different regularities to core constituent processing.

Within the domain of core constituent processing, it is the incremental interpretation of arguments that poses the greatest challenge: Whereas verbs inherently encode all of the information relevant to their interpretation, the form of an argument typically places only some constraint on how that argument will be interpreted. Note that *argument interpretation* in the sense used here does not refer to the lexical-semantic properties of an argument, but rather to that argument's relational role within the context of an entire sentence (e.g., whether it is the actor or the undergoer of the event being described). The eADM posits that argument interpretation proceeds in three hierarchically organized phases: Phase 1 encompasses basic constituent structure building, which does not give rise to any kind of relational interpretation; Phase 2 initiates argument interpretation by applying a restricted set of cross-linguistically motivated information types to associate an argument with an argument role or a position in an argument hierarchy; and Phase 3 completes the argument interpretation process by taking into account information from further domains (e.g., discourse context).

The three-phase subdivision of the model architecture that is shown in Figure 1 thus represents the hierarchically organized processing steps taking place for each individual input unit during the comprehension of a sentence. The assumption that comprehension proceeds through hierarchically organized processing phases (or modules) has been advocated by a number of researchers (e.g., Crocker, 1995; Frazier, 1978; Friederici, 2002) and is thus well established in the psycholinguistic and neurolinguistic literature. However, while sharing this basic architectural trait with these existing models, the eADM posits a completely novel internal organization of processing phases.[2]

The hierarchical organization of the processing steps in Figure 1 is indicated by arrows encoding the direction of information flow between the boxes they connect. Although we assume that processing in one phase must be completed before mechanisms be-

[2] The model that is perhaps most similar to the proposal advanced here is that put forward by Crocker (1995), in which phrase structure (i.e., word category) processing precedes thematic processing, which in turn is followed by semantic/pragmatic processing. However, the notion of thematic processing in the Crocker model differs fundamentally from the processes assumed to take place in Phase 2 of the eADM.

longing to the next phase can be initiated, the relationship between processes within the same phase is hierarchical, but not strictly serial (i.e., the completion of processing within one box is not a necessary prerequisite for the beginning of the subsequent process).

In accordance with the requirements of incremental comprehension, Figure 1 incorporates a further important subdivision into (a) representations carried forward from previous input items (rectangles) and (b) information currently being processed (rounded boxes). The latter can in turn be separated into current input properties (rounded boxes with dotted lines), and current processing steps (rounded boxes with solid lines), which include both the integration of the current input with the representations already established and the consequences arising from this interpretation (e.g., reanalysis, repair, predictions with respect to required upcoming information).

In the following, we characterize each of the three processing phases in more detail, before providing an in-depth motivation for the representations and mechanisms assumed. Note that throughout the remainder of this article, references to processing steps within the architecture in Figure 1 are indicated by the use of small capitals.

The most important properties of constituent structure (phrase structure) building in Phase 1 (TEMPLATE ACTIVATION/SELECTION) are that it (a) draws exclusively upon word category information and (b) does not yet lead to argument interpretation. We therefore assume that the output of Phase 1 is an activated phrase structure template without any relational information attached to it (i.e., no agreement, no case marking, no thematic roles, etc.).

In Phase 2 of processing, relational aspects of the form-to-meaning mapping set in and relations between the arguments themselves and between the arguments and the verb are established. Phase 2 is subdivided into two subphases: Phase 2a models how the input is used to encode features relevant for relational processing, whereas Phase 2b reflects the consequences of that encoding (i.e., relational processing per se). Consequently, we assume that Phase 2b is responsible for the effects of Phase 2 processing reported to date. Because of the different requirements imposed by predicating elements (mainly verbs) and nonpredicating elements (mainly noun phrases [NPs]), a further dissociation is undertaken between these two classes of input items. This separation reflects the different information sources encoded by the two types of elements and the interpretive consequences resulting from them:

1. NPs: Relational semantic interpretation is initiated through the assignment of prominence information (COMPUTE PROMINENCE). We use *prominence* as a cover term for information used to construct an interpretive (actor–undergoer) hierarchy between the arguments even in the absence of explicit verb-based information. Prominence assignments are based both on morphosyntactic information (morphological case, argument position) and on a small set of cross-linguistically motivated, hierarchically structured information types (e.g., animacy and definiteness). Although the set of hierarchies drawn upon for prominence assignments is assumed to be universal, the informativity of the individual information types is subject to substantial cross-linguistic variation (see below for a more detailed discussion).

2. Verbs: The verb's lexical argument representation (its logical structure [LS])[3] is associated with arguments that have already been processed (COMPUTE LINKING) by drawing upon previously computed prominence relations, agreement, and voice (active, passive). If no arguments have been encountered as yet, the COMPUTE LINKING step generates predictions derived from the LS (e.g., with respect to expected upcoming prominence relations).

In addition to the interpretive relations established by the COMPUTE PROMINENCE and COMPUTE LINKING steps, Phase 2 further serves to derive formal relations between the arguments and the verb, namely agreement (encoded as ±agrt). Arguments and verbs again differ with respect to this dimension: For the former, agreement is assigned on the basis of prominence information (ASSIGN ± AGRT), whereas the establishment of the agreement relation is a prerequisite to linking in the case of the latter (ESTABLISH AGREEMENT).

In summary, the architecture of Phase 2 allows for argument interpretation to take place both in relation to verb-based information and in the absence of this information, thus fulfilling one of the most important cross-linguistic prerequisites for incremental interpretation.

Phase 3 involves a GENERALIZED MAPPING between core relations and noncore relations or properties (e.g., world knowledge, modifier attachment, and interpretation) and provides the capacity for an evaluation of WELL-FORMEDNESS and for REPAIR processes when required. In particular, we assume that factors such as pitch accents, stress patterns, plausibility/world knowledge, frequency of occurrence, and lexical-semantic association do not modulate the processing of core relations in Phase 2. Rather, the behaviorally observed influence of these factors results from the GENERALIZED MAPPING in Phase 3, in which the outputs of core and noncore processing during Phase 2 are integrated with one another. Note also that the notion of well-formedness used here is not meant to contrast strictly with ill-formedness, but rather refers to a gradient mechanism that evaluates the acceptability of a structure under different environments (e.g., discourse context).

Finally, the model posits an overarching least-effort principle, which applies in all phases of processing and which we refer to as MINIMALITY:

> In the absence of explicit information to the contrary, the human language comprehension system assigns minimal structures. This entails that only required dependencies and relations are created.

Although motivations for minimal structure and minimal dependencies have been formulated in a number of approaches in the psycholinguistic literature (e.g., de Vincenzi, 1991; Frazier & Fodor, 1978; Gibson, 1998; Gorrell, 1995; Schlesewsky & Friederici, 2003; Sturt & Crocker, 1996), the notion of minimality at all levels assumed here is most directly related to Fodor and Inoue's minimal everything principle (Fodor, 1998; Inoue & Fodor, 1995). The consequences of the MINIMALITY principle are illustrated in detail in subsequent sections of this article.

[3] A verb's LS is a decomposed hierarchical semantic representation that encodes the relations between the argument variables in terms of their relative position with respect to basic meaning predicates such as CAUSE and BECOME (Bierwisch, 1988; Pustejovsky, 1995; Van Valin & LaPolla, 1997; Wunderlich, 1997). The LS allows the number of arguments and the hierarchical ranking between them to be derived directly from the lexical meaning of the verb.

Representational Assumptions and Their Cross-Linguistic Motivation

The processing assumptions described above are crucially constrained by cross-linguistic requirements. In particular, the representations constructed in the different processing steps meet the requirements imposed by a variety of different language types without the need to posit a great deal of abstract underlying structure or operations. In the following, we describe the cross-linguistic motivation for the representations assumed and show how these restrict the processing behavior of the model.

Phase 1: Phrase Structure Without Relational Information

The independence of relational properties from phrase structure configurations is essential to the cross-linguistic applicability of the model, as many languages (e.g., in East and South Asia) fail to show a direct correspondence between a particular structural position and a grammatical function or argument interpretation. This phenomenon is already apparent in certain European languages like German, for which it is well known that there is no designated subject position (Haider, 1993). This is illustrated by

. . . dass dem Jungen der Roller gestohlen wurde.

. . . that [the boy]$_{DAT}$ [the scooter]$_{NOM}$ stolen was.

“. . . that the scooter was stolen from the boy.” (1)

Example 1 is more acceptable than its nominative-initial counterpart, thus showing that, under certain circumstances, German allows unmarked dative-before-nominative word orders (see Fanselow, 2000, for theoretical motivations, and Grewe et al. in press, for empirical evidence). Hence, the direct association between structural and relational properties evident in languages such as English breaks down: Even in a completely unmarked German sentence, it need not be the case that the first argument is the subject, agrees with the verb, and is the actor of the event (in an active sentence). The mapping from the structural position of an argument to its interpretation is thus not straightforward in German. To account for phenomena of this type, which are very common cross-linguistically, one must separate phrase structure representations from case, agreement, and grammatical function assignment. Supporting empirical evidence for this assumption stems from the finding that an initial ambiguous argument in German may be analyzed as the argument that agrees with the verb (the subject) without simultaneously being interpreted as an actor (see Schlesewsky & Bornkessel, 2004, for a review of the relevant results). Rather, the assignment of interpretive properties such as actorhood takes place exclusively on the basis of overt morphological case marking in this language (Bornkessel, Schlesewsky, & Friederici, 2002a, 2003).

As a consequence of these cross-linguistic requirements, the eADM posits that Phase 1 of processing draws upon syntactic templates. These templates are precompiled, lexically stored phrase structure representations, which crucially encode only categorial information (i.e., word categories for lexical items and phrasal categories; Van Valin & LaPolla, 1997). From a processing perspective, the templates assumed here are thus most similar to Frazier’s proposal that the phrase structure rules for a given language may be precompiled and stored in template form (Frazier, 1989) and differ markedly from other template-based approaches to language processing, which typically also include relational information such as grammatical functions or even thematic roles (Hagoort, 2005; Townsend & Bever, 2001; Vosse & Kempen, 2000). Syntactic structure building thus encompasses template selection, template unification and, under certain circumstances, template switching. The independence of templates and morphological case/grammatical functions is shown in Figure 2 (adapted from Bornkessel & Schlesewsky, 2006).

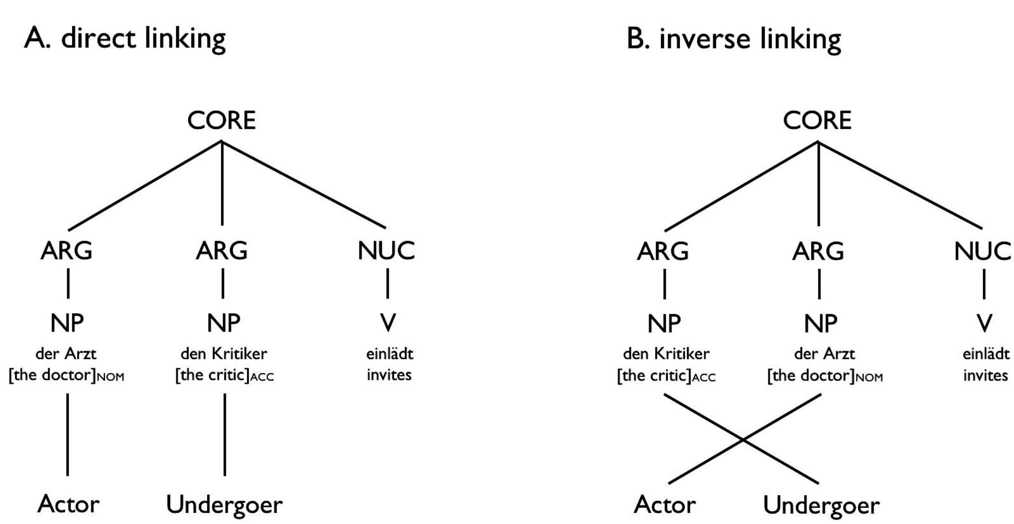

Figure 2. An illustration of the relationship between syntactic templates and the linking of arguments to generalized semantic roles. The subject-initial sentence (A) and the object-initial sentence (B) both draw upon the same transitive template but nonetheless differ in their interpretation. CORE = the minimal phrase structure domain of the clause within which the nucleus and its arguments are realized; ARG = obligatory argument (noun phrase [NP] or prepositional phrase [PP]); NUC = nucleus (essentially equivalent to head, i.e., the element subcategorizing for the arguments); V = verb.

As Figure 2 shows, both object- and subject-initial sentences in German are represented using the same two-argument syntactic template. This is the case because the template only encodes the number of arguments and their position relative to the verb. Thus, the interpretation of the arguments (i.e., the linking to the generalized semantic roles [GRs][4] actor and undergoer) is logically independent of the arguments' positions within the template. In this way, the linking process can be subject to language-particular specialization, with linking in German drawing upon morphological information and linking in English occurring on the basis of linear position, for example.

In terms of the information encoded, the templatic representations assumed here are essentially equivalent to standard phrase-structure rules and representations under the assumptions that the latter are stripped of any relational properties (e.g., c-command, grammatical functions, notions such as head-complement and head-specifier relations) and only encode word category, dominance, and precedence (primary relations in the sense of Gorrell, 1995; Sturt & Crocker, 1996). The output of Phase 1 of processing is therefore a template encoding precisely these properties, but no relational information.

Phase 2: GRs

If, as motivated above, the interpretation of an argument and its relation to other arguments is not determined by its (relative) position in the phrase structure tree, the association between the argument form and its corresponding interpretation in a sentence must be governed by some other level(s) of representation. To this purpose, a number of theoretical approaches have described (phrase structure independent) linking mechanisms from syntax to semantics (or vice versa; e.g., Dowty, 1991; Fanselow, 2001; Kiparsky, 1989; Van Valin & LaPolla, 1997; Wunderlich, 1997).

In language comprehension, semantic (or thematic) roles have also long been thought to play an important role as interface representations between syntax and semantics (e.g., Carlson & Tanenhaus, 1988; Crocker, 1995; Gibson, Hickok, & Schütze, 1994; McRae, Ferretti, & Amyote, 1997; Pritchett, 1988, 1992; Rayner, Carlson, & Frazier, 1983). However, as in theoretical linguistics, researchers have differed considerably as to the precise description of these roles (e.g., regarding their number and conceptual content and the hierarchical relations holding between them).

An attractive solution to these conceptual difficulties has been formulated on the basis of prototype theory (Rosch & Mervis, 1975) by assuming that individual semantic/thematic roles can be subsumed under prototype categories, so-called "generalized semantic roles." GRs, which have been referred to as *macroroles* (Foley & Van Valin, 1984; Van Valin & LaPolla, 1997), proto-roles (Dowty, 1991; Primus, 1999) and *hyperroles* (Kibrik, 1997), are abstractions over individual semantic roles. Thus, rather than focusing on whether an argument is, for example, a wilfully acting agent or an inadvertent causer, GRs encode the hierarchy between the participants of an event (cf. also Bresnan & Kanerva, 1989; Grimshaw, 1990; Jackendoff, 1972). Following Van Valin and colleagues (e.g., Foley & Van Valin, 1984; Van Valin & LaPolla, 1997), the eADM assumes two GRs, actor and undergoer, which correspond to the agent and patient prototypes, respectively, and which stand in a dependency relation such that the undergoer is hierarchically dependent upon the actor (Primus, 1999, p. 52). These roles and the resulting hierarchical dependencies are assigned in the COMPUTE PROMINENCE/COMPUTE LINKING steps of Phase 2.

Now consider what happens when an argument cannot be mapped onto either of these prototypical role representations. This occurs, for example, when one of the arguments bears dative case, rather than nominative or accusative (e.g., dative subjects in Icelandic, dative objects in German). Indeed, all existing grammatical theories acknowledge the exceptional status of bivalent (two argument) constructions including a dative. Although differing with regard to the specific details, generative approaches (e.g., Chomsky, 1981), classical Germanic grammarians (e.g., Helbig & Buscha, 1996), more recent functional theories such as role and reference grammar (Van Valin & LaPolla, 1997), and language typologists (Silverstein, 1976) have all assumed that, in contrast to nominative and accusative arguments, dative arguments defy interpretation through general hierarchical-structural dependencies (e.g., ±agrt or actor–undergoer). This essentially entails that a dative-marked argument is associated neither with a specific structural position nor with a particular GR. Rather, its interpretation is viewed either as encoding an opposition to the generalized role prototypes (i.e., a dative object is never an ideal, maximally affected patient, just as a dative subject is never an ideal, volitionally acting agent; Foley & Van Valin, 1984; Silverstein, 1976) or as governed by the verb alone (Chomsky, 1981).

In view of these exceptional interpretive properties of the dative, the eADM follows the tradition of classical grammarians and functionalist theories in assuming that dative-marked arguments do not correspond to a GR but rather receive their interpretation directly from the LS of the verb (for further illustration, see Figure 4, below). This leads to the prediction that constructions including a dative argument should give rise to processing behaviour that is measurably distinct from that observable for nominative-accusative structures.

Phase 2: Prominence Hierarchies

From the line of argumentation outlined with respect to phrase structure representations above, it follows that the properties drawn upon for GR assignment crucially depend on the particular language being processed (see also MacWhinney, Bates, & Kliegl, 1984). For example, while argument position is a reliable cue to GR assignment in English, the relevant information in languages such as German, Japanese, and Russian is provided by morphological case. However, cross-linguistic variation in the assignment of hierarchical dependencies between arguments does not stop at this level, as illustrated by the following example from Fore, a language of Papua New Guinea (Scott, 1978, as cited in Bisang, 2006):

Fore: interpretation determined by animacy

yaga: wá a-egú-i-e.

pig man 3sP-hit -3sA-INDIC

[4] Note that we use the abbreviation "GR" for "generalized semantic role" rather than the typical "GSR" to avoid confusion with the psychophysiological abbreviation for "galvanic skin response."

"The man kills the pig." (Not "The pig kills the man.") (2a)

Fore: case marking against the animacy hierarchy

yaga:-wama wá a-egú-i-e.

pig-ERG man 3sP-hit −3sA-INDIC

"The pig attacks the man." (Not "The man attacks the pig.") (2b)

Speakers of Fore can only interpret a simple transitive sentence such as in Example 2a as meaning that the man killed the pig, despite the fact that word order is relatively free in this language and that neither of the arguments are case marked. For the opposite relation to be expressed, in which the pig is the actor, additional case marking is required (note the ergative marking on *pig* in Example 2b). Thus, in the default case, argument interpretation in Fore is entirely determined by the animacy hierarchy (human > animate > inanimate). This example contrasts nicely with the role of animacy in English, in which this feature does not influence the establishment of hierarchical dependencies between arguments (i.e., *The vase hit the boy* can only ever mean that the boy was hit, thus showing that argument position dominates interpretation). Phenomena similar to the application of animacy in Fore can be observed for a number of other information types such as definiteness/specificity, person, and topicality in other languages (see, e.g., Comrie, 1989; Croft, 2003).

Thus, in view of the considerable cross-linguistic variation in the relational properties drawn upon for argument interpretation, we use *prominence* as a cover term for the hierarchical status of an argument as determined by the application of these various information types. As described above, the existence of such a hierarchy-based system is assumed to be universal, whereas the applicability of the individual hierarchies is language specific. Despite this cross-linguistic variation, however, only a restricted set of features (such as animacy, definiteness, person) is relevant for the computation of a prominence status.

Phase 2: The Correspondence Between Interpretive Relations and Formal Relations

A final important point on Phase 2 processing relates to the interplay between formal information (agreement) and interpretive information (GRs, prominence, linking). Whereas these dimensions cluster together in languages such as English, they show divergences in many other languages (e.g., German, Hindi, Icelandic). The most straightforward example for such a divergence is that the higher-ranking argument in interpretive terms may not always be the argument that agrees with the verb. For this reason, interpretive relations and formal relations are represented independently of one another in Phase 2 of the eADM.

With respect to the relation between these two dimensions, there is ample evidence that, when available, the prominence status of an argument determines that argument's agreement status, but not the other way around (see Bickel, 2003; Van Valin, 2005). Therefore, information flows from COMPUTE PROMINENCE to ASSIGN ± AGRT in Phase 2b for NPs. In the absence of prominence information, agreement assignment applies independently on the basis of MINIMALITY; that is, the first argument encountered is assumed to bear +agrt to guarantee for a minimal structure. (Hence, the MINIMALITY-based link between positional input in Phase 2a and ASSIGN + AGRT in Phase 2b in Figure 1.) This situation occurs, for example, in fully case-ambiguous structures in German, in which the first argument is analyzed as agreeing with the verb but not as bearing the actor role (Bornkessel et al., 2002a, 2003; Bornkessel, McElree, et al., 2004; Schlesewsky & Bornkessel, 2004).

With respect to the processing of verbs, the primary goal of Phase 2 is the computation of the linking between the argument hierarchy represented in the verb's LS and the argument(s) already processed. A prerequisite to this step, however, is that for languages with agreement, the agreement properties of the verb are compatible with the information processed so far, as determined by ESTABLISH AGREEMENT. The verb's agreement properties are compatible with the previous input if the argument bearing +agrt matches the features of the verb or, in case this condition is not met, if there is a possible alternative assignment of +agrt. In both cases, processing is relayed to the COMPUTE LINKING step, which, in the second case, will be associated with increased processing costs because of the required conflict resolution. Should there be no alternatives for the reassignment of +agrt in the case of a mismatch (e.g., because the argument bearing +agrt is unambiguously an actor), processing fails at the ESTABLISH AGREEMENT stage, and no linking is initiated. For languages without agreement (e.g., Chinese), the ESTABLISH AGREEMENT step is vacuously satisfied.

A First Illustration

Before turning to a detailed discussion of the model's neurocognitive processing correlates, we illustrate the processing mechanisms described above on the basis of an example from English:

Richard invited the gardener. (3)

The step-by-step description of the processing operations applying in Example 3 is given in Figure 3. Note that we have chosen to illustrate how the model works on the basis of a straightforward example at this point. Structures giving rise to increased processing difficulties will be discussed in detail in the following sections.

Neurophysiological Foundations

In this section, we present empirical evidence for the architecture of the eADM, drawing primarily on neurophysiological data in the form of event-related brain potential (ERP) measures. Although model-theoretic assumptions regarding the language comprehension architecture have been examined with a variety of experimental methods (cf. Carreiras & Clifton, 2004; Townsend & Bever, 2001), the advent of techniques allowing for a mapping of sentence processing mechanisms to their neural foundations (ERPs, functional MRI) has led to a wealth of new findings from a variety of languages, which provide rich detail regarding the temporal and spatial properties of comprehension processes. In view of the multidimensionality of the data provided by these methods, the resulting observations are often diverging and seemingly counterintuitive. However, as we argue below, these apparent incompatibilities often provide important cues to the underlying implementation of certain processes, which may then be linked to behavioral observations (e.g., sentence acceptability ratings or reading times).

In the following, we attempt to provide a unified explanation for a number of apparently diverging neurophysiological findings in

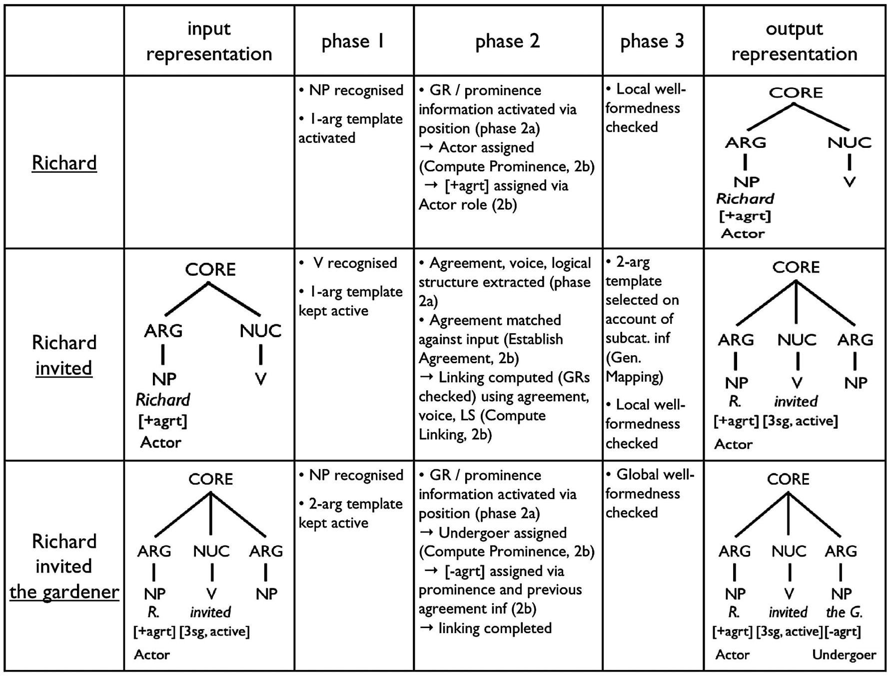

Figure 3. Summary of the incremental processing steps involved in the comprehension of Example 3. CORE = the minimal phrase structure domain of the clause within which the nucleus and its arguments are realized; ARG = obligatory argument (noun phrase [NP] or prepositional phrase); NUC = nucleus (essentially equivalent to head, i.e., the element subcategorizing for the arguments); V = verb; R. = Richard; G. = gardener; arg = argument; agrt = agreement; inf = information; 3sg = third person singular.

terms of the eADM. At the same time, these results, which are summarized in Table 1, are used to illustrate the internal organization of the model. The major focus lies on the description of Phase 2, which is the locus of the architectural claims at the heart of the eADM.

For each processing step assumed within the model, Table 1 lists the associated ERP component(s), the languages drawn upon in the discussion of the effect in question and the relevant examples. In the following, we discuss each processing phase and its respective submechanisms in turn.

Phase 1

The assumption of an initial stage of comprehension taking only word category information into account dates back to the late 1970s and early 1980s (e.g., Frazier, 1978; Frazier & Rayner,

Table 1
Summary of the Extended Argument Depency Model's Neurophysiological Correlates

Processing step	ERP component	Language	Example
Phase 1			
Template activation/selection	Early left-anterior negativity	English, German, Dutch	4, 5
Phase 2			
Compute prominence (mismatch with previous prominence information)	N400	English, German, Russian	6, 7, 8
Compute prominence (mismatch with template)	Scrambling negativity	German	9
Assign ± Agrt	LAN	English, Finnish	11, 12
Establish Agreement (mismatch with GR information)	LAN	English, Dutch, Italian	13
Compute linking (GR mismatch)	Early positivity (P345)	German, Dutch, English	15, 16, 17, 18
Compute linking (agreement mismatch)	N400/P600	German	14, 19, 20
Compute linking (hierarchy mismatch)	LAN	German	21
Phase 3			
Generalized mapping	Late positivity	Dutch, English, German	22, 23, 24
Well-formedness/repair	Late positivity	English, German	25, Footnote 9

Note. ERP = event-related brain potential; LAN = left-anterior negativity; agrt = agreement; GR = generalized semantic roles.

1982). This hypothesis was later confirmed by experiments with ERPs, which revealed an early anterior negativity (ELAN; between 150 and 200 ms post-critical-word onset) in response to word category violations (Hahne & Friederici, 1999; Neville, Nicol, Barss, Forster, & Garrett, 1991).

The word category violations discussed in the literature as evidence for an initial processing phase essentially result from the principled inability to integrate an input item into the current syntactic structure. For example, Neville et al. (1991) examined violations such as *Max's of proof the theorem* and observed an ELAN at the position of *of.* Here, a processing conflict results because English offers no way of integrating a preposition adjacent to a possessive proper noun. By contrast, the processing of categories that are not predicted but nonetheless allow a possible integration do not engender an ELAN (cf. Friederici, 2002). In the eADM, these crucial properties of Phase 1 are modeled in terms of syntactic templates, that is, precompiled phrase structures encoding only category information. From this perspective, the ELAN reflects a template selection failure, which arises when the template inventory of the language being processed does not contain a template that is compatible with the current input string. Unexpected continuations, by contrast, require only a template switch.

Further evidence that Phase 1 effects reflect template selection failures stems from one of the classical ERP paradigms on syntactic processing (Osterhout & Holcomb, 1992, 1993). Using auditory presentation, Osterhout and Holcomb (1993) contrasted sentences such as in Examples 4a and 4b:

The broker persuaded to sell the stock *was* sent to jail. (4a)

*The broker hoped to sell the stock *was* sent to jail. (4b)

At the position of *was* in Example 4b, Osterhout and Holcomb observed an anterior negativity that reached significance between approximately 300 and 500 ms post word onset in addition to a late positivity. As in the examples described above, processing breaks down at this point because there is no suitable template in the template inventory for English. Note that the latency of the effect presumably results from the particular properties of auditory presentation (cf. also Friederici & Meyer, 2004).

The strongest evidence for the hierarchical dominance of Phase 1 over Phase 2 stems not from the absolute latency of the ELAN in comparison with ERP effects related to Phase 2 processing, but from the fact that this component is not influenced by information types that become available only in later processing stages, that is, verb-based semantic or argument-structure restrictions (Frisch, Hahne, & Friederici, 2004; Hahne & Friederici, 2002). This conclusion has been questioned on the basis of a recent ERP experiment (van den Brink & Hagoort, 2004), which used auditory presentation to examine combined word category and plausibility violations as in Example 5. The category of the critical word (encoded in the suffix —*de*) became available approximately 300 ms after word onset (termed the *category violation point*).

*Het vrouwtje veegde de vloer met een oude *kliederde* gemaakt van twijgen.

The woman wiped the floor with an old messed made of twigs. (5)

van den Brink and Hagoort observed an N400 in response to the (semantically) incongruent fragment with an onset clearly before the category violation point. This effect was followed by an anterior negativity and a late positivity, both of which can be analyzed as reflections of the category mismatch induced by the suffix, thus leading them to argue that word category processing need not precede the processing of plausibility information. However, as the stem of the word is compatible with the predicted noun analysis, there is no reason to delay incremental processing until the end of the word (especially in a highly constrained phrase structure context such as determiner + adjective). Therefore, these data do not contradict the assumptions advanced here. Perhaps even more important, the data show that, within a single word, an N400 does not block an ELAN, whereas it has been shown that an ELAN blocks an N400 (e.g., Hahne & Friederici, 2002). This asymmetry attests to the hierarchical predominance of Phase 1 (which, in most cases, is paralleled by temporal precedence).

In summary, the neurophysiological evidence for a primacy of word category-based processing in Phase 1 of comprehension is in good agreement with the cross-linguistic motivation for separating phrase structure representations from representations encoding relational information (see the section on representational assumptions above).

Phase 2

As discussed above, the primary focus of the eADM lies in Phase 2, which encompasses relational processes applying to arguments and verbs. In accordance with the dissociation between argument and verb processing introduced above, this section first focuses on correlates of the processes involved in argument comprehension before moving on to verb processing mechanisms. In each case, the discussion is subdivided according to the individual processing steps shown in Figure 1. Note also that the discussion of Phase 2 processes focuses on Phase 2b. Because Phase 2a is primarily concerned with the activation and extraction of relevant features from the current input item, all relevant computational steps take place in Phase 2b.

Argument Processing

As is apparent from Figure 1, we assume that the aim of argument processing in Phase 2 is essentially twofold: On the one hand, the processing system endeavors to compute a prominence status for the argument under consideration; on the other, it assigns agreement properties in the form of the feature ±agrt. In essence, these two processes amount to an analysis of the argument in interpretive (prominence) and formal (agreement) terms, respectively. As discussed above, prominence and agreement are interconnected when sufficient information is available for the assignment of a prominence status (leading to the subsequent assignment of either +agrt or −agrt). Whenever prominence cannot be computed because of lack of information, agreement is assigned via MINIMALITY and, thereby, independently of prominence. We discuss the neurophysiological manifestations of the COMPUTE PROMINENCE and ASSIGN ± AGRT steps in turn in the following.

Compute prominence. The computation of prominence draws upon a number of different features, the informativity of which differs depending on the particular language under consideration. One information type that is predicted to show a particularly strong influence cross-linguistically is animacy. Not only is the distinction between animate and inanimate entities central to cross-linguistic generalisations as described above, it is also important in general conceptual terms (Rakison & Poulin-Dubois, 2001). In online comprehension, animacy should therefore interact with other information types that are important for the computation of prominence in a given language.

Previous ERP findings indeed speak in favor of an interaction of animacy with morphological case in German and with argument position in English. The relevant sentence examples are shown in Examples 6 and 7:

. . . welchen Lehrer *der Zweig* streifte.

. . . [which teacher]$_{ACC}$ [the twig]$_{NOM}$ brushed

". . . which teacher the twig brushed." (6)

The *novelist* that . . . (7a)

The *movie* that . . . (7b)

For German, embedded *wh*-questions with an initial animate accusative argument and a second inanimate nominative argument such as in Example 6 have been shown to elicit a centro-parietal negativity (N400) at the position of the second NP in comparison with an animate NP in the same position (Frisch & Schlesewsky, 2001; Roehm, Schlesewsky, Bornkessel, Frisch, & Haider, 2004). We propose that this effect is the result of the increased processing cost associated with having to assign an actor role to an inanimate argument, which arises in the COMPUTE PROMINENCE step in Phase 2b for NPs. More precisely, when the accusative *wh*-phrase is initially assigned the undergoer role (because of its morphological marking), the application of the prominence hierarchies gives rise to the prediction of an upcoming, ideal actor.[5] When the second NP is subsequently encountered, however, it does not entirely fulfill this expectation because it is inanimate. The assignment of a more prominent status (and of the actor role) is therefore more costly, as is reflected in the N400 effect.

Evidence from English attests to the fact that similar processing costs may come about when positional rather than morphological information is informative with respect to prominence assignment. Using sentences such as in Example 7, Weckerly and Kutas (1999) contrasted the processing of animate and inanimate subjects in an ERP study. Because of the visual, word-by-word presentation mode employed, the sentence-initial determiner *the* was processed and integrated before the following noun was encountered. Thus, on the basis of its linear position, the first determiner leads to an assignment of a highly prominent status (and of the actor role) to NP1. When the subsequent noun is encountered, this either straightforwardly fits the actor assignment, as in Example 7a, or it is not ideally compatible with it, as in Example 7b. Similar to the German sentences discussed above, the processing difficulty resulting in the COMPUTE PROMINENCE step is reflected in an N400 effect.

These findings establish the N400 as an electrophysiological correlate of increased processing difficulty arising in the COMPUTE PROMINENCE step. Specifically, we assume that this effect reflects a mismatch arising between prominence information computed in previous processing steps and the features of the current input item. In this way, the N400 effects described do not simply reflect a mismatch between the actor role (or nominative case) and inanimacy per se. Converging support for such an interpretation stems from a further study in German, in which an initial inanimate nominative did not yield an increased N400 (Ott, 2004).

Further confirmation of the association between the COMPUTE PROMINENCE step, previously computed prominence information, and the N400 stems from a series of experiments on so-called "double case" violations, an example of which is given in Example 8.

*Welcher Lehrer besuchte der Priester am Sonntag?

[which teacher]$_{NOM}$ visited [the priest]$_{NOM}$ on Sunday (8)

Example 8 is ungrammatical because both sentential arguments bear nominative case, a constellation that is not possible in German. At the position of the second argument, this type of violation elicits a biphasic N400/late positivity pattern (Frisch & Schlesewsky, 2001, 2005). Although we interpret the late positivity as an index of processing difficulty in the WELL-FORMEDNESS evaluation step in Phase 3 (see below), the N400 observed here arises from a mismatch between previously computed prominence information (i.e., assignment of high prominence to the first NP on the basis of its nominative case marking) and current input information (i.e., case morphology implying a similarly prominent status). This interpretation receives converging support from the finding that the N400 effect engendered by double case violations may be modulated by information relevant for the computation of prominence. For example, in double nominative constructions including an animate and an inanimate argument, no N400 difference is apparent, whereas the late positivity as an expression of ill-formedness remains (Frisch & Schlesewsky, 2001). Thus, the N400 very precisely mirrors the degree of interpretive conflict arising in the COMPUTE PROMINENCE step (see also Frisch & Schlesewsky, 2005).

A second neurophysiological correlate of the COMPUTE PROMINENCE step is observed when the prominence status of an argument is not compatible with previously established phrase structure representations. As an illustration, consider the following sentence fragment:

. . . dass den Lehrer . . .

. . . that [the teacher]$_{ACC}$ . . . (9)

At the position of the complementizer *dass*, the comprehension system selects a one-argument subordinate clause template in accordance with MINIMALITY. When the accusative NP *den Lehrer* is encountered in a subsequent processing step, it is integrated into the single argument position made available by the template. This does not lead to a processing problem in Phase 1, as the categorical

[5] The ability to predict an ideal actor from the processing of an undergoer can again be motivated on the basis of cross-linguistic considerations. Specifically, Comrie (1989) described the properties of transitive (two argument) relations across languages by means of the following generalization:

> In the transitive construction, there is an information flow that involves two entities, the A [Agent] and the P [Patient] . . . the most natural kind of transitive construction is one where the A is high in animacy and definiteness, and the P is lower in animacy and definiteness; and any deviation from this pattern leads to a more marked construction. (Comrie, 1989, p. 128).

properties of the argument (i.e., NP) match those required by the template representation (recall that only word category is relevant here). In Phase 2, however, the following problem arises: Because of its accusative case marking, the NP must be assigned the undergoer role in the COMPUTE PROMINENCE step. As the GR-dependency entailed by this assignment—in combination with the fact that German does not allow subjects to be dropped—indicates that a second (actor) argument must follow, the output of the COMPUTE PROMINENCE step is no longer compatible with the currently active one-argument template. In terms of ERP measures, this conflict is reflected in a fronto-central negativity with a slight focus to the left that is observable between approximately 300 and 500 ms post argument onset (Bornkessel et al., 2002b; Rösler et al., 1998; Schlesewsky et al., 2003). Note that this effect cannot be straightforwardly described as either a left-anterior negativity (LAN) or an N400, as it is associated with a distribution that is intermediary between that of these two well-established components. Because of its appearance in clause-medial word order variations in German ("scrambling"), it has been termed the "scrambling negativity."

Further evidence in favor of the interpretation of the scrambling negativity advanced above stems from an experiment reported by Bornkessel et al. (2002b), in which the scrambling of accusative arguments (as in Example 9) was compared with that of dative arguments (as in Example 10).

. . . dass dem Lehrer . . .

. . . that [the teacher]$_{\text{DAT}}$ . . . (10)

In contrast to the accusative NP in sentences such as in Example 9, the dative NP in structures analogous to Example 10 did not elicit a measurably different ERP response to a nominative NP in the same position. However, whereas the accusative implies the presence of a second argument as discussed above, this is not the case with the dative, which is compatible with an intransitive template (e.g., in a passive construction: *dass dem Lehrer geholfen wurde*, "that [the teacher]$_{\text{DAT}}$ helped was"). This finding thus supports the notion that the scrambling negativity results from a mismatch between the output of the COMPUTE PROMINENCE step and the current template representation, rather than constituting a more general response to an unexpected case marking. Generalizing this analysis to a cross-linguistic perspective, the model predicts that (unambiguously marked) initial objects should give rise to a scrambling negativity only when they are incompatible with a minimal phrase structure. This is particularly relevant for the many languages which do not require an overt realization of the subject argument, such as Turkish, Japanese, Hindi, and Chinese (see Cross-Linguistic Predictions, below, for further details).

Assign ± agrt. Correlates of the ASSIGN ± AGRT processing step can be observed when COMPUTE PROMINENCE does not give rise to any difficulties (e.g., because no information that is informative in this regard is available), but an agreement mismatch arises nonetheless. This is the case, for example, in structures such as English (see Example 11; from Coulson et al., 1998), which are superficially similar to the double case violations discussed above.

*The plane took *we* to paradise and back. (11)

In contrast to structures such as in Example 8 in German, Example 11 does not yield a mismatch with respect to COMPUTE PROMINENCE since morphological case is no longer informative with respect to prominence properties in English (in contrast, presumably, to earlier stages of the language, see Allen, 1995). We assume that this is the case even for pronouns, which do show remnants of morphological case. In terms of positional information, which is informative for prominence assignment in English, no conflict is induced either, since NP1 precedes NP2. However, in the subsequent ASSIGN ± AGRT step, the morphological form of the pronoun turns out to be incompatible with the −agrt feature, which is required because of the position in which this argument is encountered (i.e., the preverbal argument must invariably bear +agrt if the structure is to be grammatical). This conflict is expressed in the form of a LAN between approximately 300 and 500 ms (Coulson et al., 1998) followed by a late positivity. As for the German example in Example 8, we interpret the late positivity as an expression of the WELL-FORMEDNESS check in Phase 3 of processing. More interesting, however, an interpretation of the LAN in Example 11 terms of an agreement mismatch is highly compatible with the finding of a LAN for verb-induced agreement matches (see below).

We therefore propose that the difference between the LAN for English structures such as in Example 11 and the N400 for German structures such as in Example 8 reflects a neurotypological variable, namely whether morphology is informative for the computation of prominence. In languages with morphological informativity, double case violations yield a conflict in the COMPUTE PROMINENCE processing step, and similar constructions in languages without morphological informativity lead to processing difficulties in ASSIGN ± AGRT because of the vacuous fulfillment of COMPUTE PROMINENCE.

An interpretation of the data pattern along these lines leads to the prediction that the difference between LAN and N400 effects in double case violations may be used as a diagnostic tool for the processing-related informativity of morphological information in a particular language. A rather impressive demonstration that this indeed appears to be the case—that is, that the question of whether morphological case plays a role in the online computation of prominence in a given language is not trivial—stems from recent data on double case violations in Finnish, for example:

*Kuka komisaari kehui etsivä radiossa?

[which policeman]$_{\text{NOM}}$ praised [the detective]$_{\text{NOM}}$ on-the-radio (12)

In terms of its surface properties, Finnish appears much more similar to German than to English: It has a rich system of morphological case marking and is typically described as a free-word-order language. Nonetheless, Finnish shows a LAN/late positivity pattern for structures such as in Example 12 (Frisch et al., 2005). In terms of the eADM, this finding indicates that double case violations give rise to an agreement rather than a prominence mismatch in this language and, therefore, that morphological case is not used for prominence computation. The model thus generates the prediction that—in contrast to commonly held assumptions about Finnish—this language should show strong positional effects with respect to core arguments and the verb. A closer examination of Finnish word order preferences shows that this prediction is indeed borne out: Although allowing a number of word order permutations, this language displays a strong tendency for a subject-verb (SV) order (i.e., object-subject-verb [OSV] is judged as being relatively acceptable, but OVS is not). Finnish therefore shows a word order restriction that is absent in German. This positional restriction appears to override a possible role of morphological case in the computation of prominence in Finnish. As a consequence, the second argument in sentences such as in Example 12 engenders an agreement mismatch similar to that observed in English. By contrast, a further language with morphological case marking and no analogous word order restrictions (Russian) was shown to pattern with German just as predicted (Frisch et al., 2005).

In summary, the comparison between German, English, Finnish and Russian suggests that qualitative differences in neurophysiological processing patterns for superficially similar constructions in different languages may provide an entirely new (*neurotypological*) perspective on similarities and differences between the processing strategies applied in these languages.

Verb Processing

Having examined the Phase 2 processing routines for arguments, let us now turn to the mechanisms applying to predicating elements (verbs). When a verb is encountered and identified as such (Phase 1), its LS, voice and agreement features are extracted in Phase 2a. In Phase 2b, the verb is integrated with all previously available information concerning sentential arguments. Thus, agreement relations are established (Establish Agreement) and argument linking (i.e., argument interpretation by way of an association of the argument with a position in the verb's LS) takes place (Compute Linking). Again, we discuss these two processing steps in turn.

Establish agreement. Consider first the Establish Agreement step, which is probably the best examined process in terms of neurophysiologically-based studies in a variety of languages. For a violation of subject–verb agreement, the literature consistently reports a transient LAN followed by a late positivity (cf., for example, de Vincenzi et al., 2003, for Italian; Hagoort & Brown, 2000, for Dutch; Osterhout & Mobley, 1995, for English; Roehm, Bornkessel, Haider, & Schlesewsky, 2005, for German). This type of violation is illustrated in Example 13, which is from de Vincenzi et al., (2003):

Il cameriere anziano serve/servono con espressione distratta.
the waiter old serves/serve with look vacant
'The old waiter serves/serve with a vacant look.' (13)

Like English, Italian is a position-based language. Recall from the discussion of Finnish, above, that a certain degree of word order freedom does not contradict position-based interpretation. In particular, in a language without morphological argument encoding such as Italian, position must be the primary source of information for (local) argument interpretation.

Consequently, in Phase 2 of processing, the first NP in Example 13 *il cameriere anziano* is assigned the actor role via Compute Prominence, which is accessed via positional information. On the basis of this GR assignment, NP1 also receives the feature +agrt in the subsequent Assign ± agrt step. When the processing system then encounters the verb *servono*, which does not agree with the first argument in terms of number, a mismatch arises in the Establish agreement step, thus yielding a LAN effect. Of importance is that it is not likely that this effect simply resulted from the recognition of an ungrammaticality. As Bates (1976) pointed out, an initial object preceding the verb is, in fact, a rather frequent word order in Italian because of this language's predisposition toward subject drop in combination with the possibility of object topicalization.

Similar findings (LAN effects followed by late positivities) have been reported for agreement mismatches in other position-based languages such as English (e.g., Coulson et al., 1998; Osterhout & Mobley, 1995) and Dutch (Hagoort & Brown, 2000). Note that the observation of a LAN for a mismatch in the Establish Agreement step is highly consistent with the LAN effects resulting from irresolvable inconsistencies in the Assign ± agrt step for argument processing in languages without morphological informativity.

A comparison between de Vincenzi et al.'s (2003) finding and an identical experimental manipulation in German again reveals differences between positional languages of the English, Italian, or Dutch type and languages such as German, in which the position of a case-ambiguous core argument does not lead to the assignment of prominence information (and, thereby, GRs). Consider the following German sentence fragment, which is superficially very similar to the Italian sentence in Example 13 (from beim Graben, Schlesewsky, Saddy, & Kurths, 2000):

Welche Studentin besucht/besuchen . . .
[which student]$_{AMB}$ visits/visit . . . (14)

As in the example from de Vincenzi et al.'s experiment, Example 14 includes an initial NP that is preferentially interpreted as—but need not necessarily be—the argument that agrees with the finite verb. In contrast to Italian, however, in which the Assign ± agrt step was reached via Compute Prominence, the assignment of +agrt to *welche Studentin* in German is a consequence of the Minimality principle because of the first argument's ambiguous case marking. Thus, this assignment is crucially not tied to the assignment of a GR. Consequently, when a verb not matching the first NP in terms of agreement properties is encountered in the following position, there is no mismatch between the GR information and the agreement information, because no GRs have been assigned. The eADM therefore predicts that there should be no LAN effect in sentences such as Example 14. Indeed, beim Graben et al. (2000) only observed a P600 for *besuchen* versus *besucht*. To provide a functional interpretation of this component, we must first discuss the second processing step in Phase 2b for verbs (Compute Linking). We shall then return to the question of what the P600 in Example 14 reflects in the section on the interaction between Establish Agreement and Compute Linking (see also the more general section on the mapping between ERP components and processing mechanisms below).

Compute linking. As described above, the Compute Linking step serves to map arguments or argument hierarchies onto the hierarchical argument structure of the verb (its LS), taking into account GRs, agreement, and voice. If no GR assignments have been undertaken when the verb is reached, these must be accomplished in the Compute Linking step as a prerequisite to linking proper.

Let us first consider the case in which GRs have already been assigned, but these assignments turn out to be incompatible with the lexical information of the verb. This is the case, for example, in German sentences with (clause-final) dative object-experiencer verbs.

. . . dass der Dirigent den Sängerinnen auffällt.

. . . that [the conductor]$_{NOM}$ [the singers]$_{DAT}$ is-striking-to

". . . that the conductor is striking to the singers." (15)

In contrast to the typical mapping between cases and generalized roles, the verb *auffällt* ("to be striking to") calls for an assignment of the undergoer role to the nominative-marked argument (*der Dirigent*), which also agrees with the verb. In other words, the argument primarily responsible for the state of affairs described by the sentence is now the object, rather than—as is typically the case—the argument that agrees with the verb in person and number (the subject). This analysis is confirmed by the observation that verbs of this type can undergo neither passivization nor nominalization (see Jackendoff, 1972).[6] Because of these exceptional linking properties of dative object-experiencer verbs, increased processing difficulties are obtained in the COMPUTE LINKING step when the verb *auffällt* is processed in Example 15: The nominative argument must be reinterpreted from an actor to an undergoer. This thematic reanalysis is reflected in an early parietal positivity (Bornkessel et al., 2002a, 2003). Of importance is that this effect occurs only in unambiguously case-marked sentences (Bornkessel et al., 2002a) and is independent of word order (Bornkessel et al., 2003), thus suggesting that (in German) it exclusively depends upon the application of morphological case in the assignment of prominence/GR information.

Cross-linguistic support for an association between the early positivity and a GR-mismatch/reanalysis in the COMPUTE LINKING processing step stems from Dutch, a language which can be assumed to behave similarly to English and Italian in that it lacks morphological case marking and thus draws upon a positional strategy. For Dutch, Lamers (2001) observed an early positivity at the position of the verb in sentences such as in Example 16b.

De oude vrouw in de straat verzorgde hij vrijwel elke dag.

the old woman in the street took-care-of he$_{SUBJ}$ almost every day

'He took care of the old woman in the street almost every day.'(16a)

Het oude plantsoen in de straat verzorgde hij vrijwel elke dag.

the old park in the street took-care-of he$_{SUBJ}$ almost every day

'He took care of the old park in the street almost every day.' (16b)

In both Examples 16a and 16b, the initial argument is assigned the actor role on the basis of its position and, consequently, the feature +agrt. When the verb *verzorgde* is subsequently encountered, there is no problem with respect to the agreement relation between the first argument and the verb and, thus, no analogous ERP effect to the Italian sentence in Example 13 (i.e., no LAN). Processing therefore proceeds to the COMPUTE LINKING step, which in the case of Example 16a, is also unproblematic. In Example 16b, however, the verb information reveals that the supposed actor (NP1) cannot be linked to the appropriate position in the verb's LS, because this would violate an animacy restriction (inanimate entities such as parks cannot take care of someone). Thus, the first argument must be reinterpreted as an undergoer. As in German, this reassignment yields an early positivity for Example 16b in comparison with Examle 16a, albeit as a consequence of positional rather than morphological information.

In view of these findings from Dutch and German, it is not surprising that a recent study on English observed a similar early positivity for the reinterpretation of a presumed actor argument as an undergoer (Phillips, Kazanina, & Abada, 2005). In Example 17a, the relative pronoun *who* is assigned an actor interpretation on the basis of its initial position, which is disconfirmed by the appearance of the subsequent relative clause subject. The required revision is reflected in an early positivity in comparison with an identical item in a control sentence (see Example 17b).

I wonder who the man . . . (17a)

I wonder whether the man . . . (17b)

In summary, the distribution of early positivity effects reflecting GR mismatches/ revisions provides further converging support for the notion that different information types (case morphology and position) lead to an assignment of similar features (GRs/prominence information) in different languages.

The explanatory capacity of compute linking: Early positivities in grammatical function reanalyses. Readers familiar with the ERP literature on sentence comprehension will likely have noticed the similarity between the early positivity described as a correlate of COMPUTE LINKING in the preceding paragraphs and the so-called "P345," an early parietal positivity first reported by Mecklinger et al. (1995) for grammatical function reanalyses in German relative clauses such as

Das ist die Journalistin, die die Sekretärinnen informiert haben.

this is the journalist who$_{AMB.SG}$ [the secretaries]$_{AMB.PL}$ informed$_{-ACC}$ have$_{PL}$

"This is the journalist whom the secretaries informed." (18)

Example 18 is a classical example of a grammatical function ambiguity; that is, both the relative pronoun *die* and the second argument in the relative clause are ambiguous with respect to case and, thereby, subject- or objecthood. When the clause-final auxiliary is encountered, number agreement information disambiguates the relative clause towards the (dispreferred) object-initial reading. The question therefore arises why this dispreferred disambiguation in a case-ambiguous sentence should yield a very similar ERP effect to that observed for GR mismatches in unambiguously case-marked sentences (recall that we assume no preverbal GR assignment in case-ambiguous structures in German). Indeed, as

[6] Note that, in contrast to German, English lacks true object-experiencer verbs, thereby rendering an exact translation of the German examples impossible. While English verbs such as *frighten* are often labeled as "object-experiencer verbs," verbs of this type are ambiguous between a true object-experiencer reading (in which the experiencer outranks the stimulus) and a causative reading, in which the subject (causer) thematically outranks the object (experiencer; Grimshaw, 1990; Pesetsky, 1994). As a result of this ambiguity, verbs such as *frighten* allow passivization (*The mask frightened the boy* vs. *The boy was frightened by the mask*). In German, the availability of case marking leads to a morphological dissociation between the two classes of experiencer verbs: Whereas true object-experiencer verbs assign dative case, ambiguous verb of the *frighten* type assign accusative case.

we will outline in the following, both effects can be explained in a unified way.

A first important observation with respect to the P345 for grammatical function reanalysis is that this effect is only observable in relative clauses (see below for further discussion of other constructions). It can therefore be described neither as a general marker of grammatical function reanalysis nor as a reflex of grammatical function reanalysis in a particular sentence structure (because embedded *wh*-questions, which are assumed to be structurally identical to relative clauses, show different ERP effects; e.g., Bornkessel, Fiebach, & Friederici, 2004a). In the context of the eADM, the nature of the component observable for relative clauses leads to the hypothesis that, in contrast to all of the other German grammatical function ambiguities discussed in the literature, relative clauses already allow for an assignment of GRs before the verb is encountered. This assumption appears plausible in view of the fundamental distinction between relative clauses and other clause types that results from the dependency between the relative pronoun and its antecedent head noun. Thus, many researchers have assumed that, beside the obligatory matching processes applying between the head noun and the relative pronoun (e.g., relating to gender and number), there is also a transfer of GR-relevant features such as case (Fanselow, Schlesewsky, Cavar, & Kliegl, 1999; Sauerland & Gibson, 1996; Schlesewsky, 1997; Smolensky & Stevenson, 2005), grammatical function (Grober, Beardsley, & Caramazza, 1978), or perspective (MacWhinney, 1999; MacWhinney & Pléh, 1998). In this way, even case-ambiguous relative pronouns may indeed already be associated with a GR when the verb is processed, albeit via a different mechanism than the (case or position-based) role assignments previously discussed.

Now consider what happens when the auxiliary is reached in a sentence such as in Example 18. In Phase 2, ESTABLISH AGREEMENT yields a mismatch because the relative pronoun, which was assigned +agrt via MINIMALITY, does not match the agreement properties of the verb. No LAN ensues, because the agreement feature was not assigned via a GR (see the discussion of Examples 13 and 14). Instead, when processing is relayed to COMPUTE LINKING, there is a mismatch between the presumed (antecedent-based) GR assignment and the required GR, thus engendering an early positivity. Thus, the early positivity in Example 22 (see below) is the result of the somewhat peculiar constellation arising in relative clauses, in which a GR has been assigned via an atypical, core-external mechanism, and the same argument receives +agrt on the basis of the earlier, core-internal operations based on the MINIMALITY principle. This accounts for the general difference between grammatical function reanalyses in relative clauses as opposed to all other sentence types.

The interaction between establish agreement and compute linking. As is apparent from Figure 1, the ESTABLISH AGREEMENT processing step is one of the crucial input sources for COMPUTE LINKING. Particularly interesting and important examples of an interaction between these two processing steps therefore arise when a processing problem in the ESTABLISH AGREEMENT step leads to higher costs with respect to the computation of argument linking. The best-known phenomenon of this type is the reassignment of grammatical functions via agreement properties. As many studies have shown (e.g., Bader & Meng, 1999; de Vincenzi, 1991; Frazier & Flores d'Arcais, 1989; Schriefers, Friederici, & Kühn, 1995), subject-object ambiguities reliably lead to a subject-first strategy. Thus, the first argument encountered by the processing system is initially analyzed as the argument that agrees with the verb (the subject in traditional terms), and a subsequently required revision of this assumption engenders increased processing costs. Grammatical function ambiguities in *wh*-questions and relative clauses have already been illustrated in Examples 14 and 18, respectively. Two further examples (complement clauses) are given in Example 19. Note that the subscripts ACC(usative) and DAT(ive) in this example refer to the object case assigned (subcategorized for) by the verb in question.

. . . dass Gisbert Studentinnen ausraubten.
. . . that Gisbert$_{\text{AMB.SG}}$ students$_{\text{AMB.PL}}$ robbed$_{\text{-ACC.PL}}$
". . . that students robbed Gisbert." (19a)

. . . dass Gisbert Studentinnen folgten.
. . . that Gisbert$_{\text{AMB.SG}}$ students$_{\text{AMB.PL}}$ followed$_{\text{-DAT.PL}}$
". . . that students followed Gisbert." (19b)

In both sentences in Examples 19) and 14, the first NP is assigned +agrt via MINIMALITY. When the verb is encountered, however, this assignment cannot be upheld because the first NP is singular while the verb bears plural agreement features. Thus, a mismatch arises in the ESTABLISH AGREEMENT step, which does not, however, lead to a LAN because no GRs were previously assigned to the case-ambiguous arguments. In a next step, the processing system must then proceed to COMPUTE LINKING so that the arguments can be interpreted. However, because of the agreement mismatch, the GR computation—and thereby the entire linking process—is not straightforward and essentially requires not only a reversal of the +agrt assignment but also an assignment of the actor role to the second argument. From a bird's-eye perspective, therefore, Examples 14 and 19 involve a similar type of processing conflict.

Nonetheless, the disambiguation of grammatical function ambiguities is associated with a rather complex pattern of results. Thus, the processing conflicts in Examples 14, 19a, and 19b result in distinct ERP signatures. Whereas Examples 14 and 19a elicit a late parietal positivity (P600; e.g., beim Graben et al., 2000; Bornkessel, McElree, et al., 2004; Friederici & Mecklinger, 1996), Example 19b gives rise to a centro-parietal negativity between 350 and 550 ms (N400; Bornkessel, McElree, et al., 2004; Leuckefeld, 2005, for the auditory modality). These striking differences in terms of electrophysiological responses suggest that, despite their superficial similarity, the processing conflicts in the two examples in Example 19 cannot be fully analogous.

What might be the source of this variation? On the one hand, it appears highly unlikely that the ESTABLISH AGREEMENT step should be held responsible for the different effects, as the agreement mismatch is the same in all cases (for supporting empirical evidence see Bornkessel, McElree, et al., 2004, Experiment 3). Similarly, differences in the target structure to be computed by the reanalysis also cannot provide an adequate explanation, as the target structures required by Examples 19a and 19b are identical. Furthermore, the target structure for Example 14 clearly differs from that for Example 19a, but the two processing conflicts nonetheless yield the same effect.

In terms of the Compute Linking step, however, an important difference arises between Examples 19a and 19b. Recall from the section on GR representations that the eADM assumes a principled distinction between two-argument structures with accusative and dative verbs. Whereas the former assign two GRs, namely actor and undergoer, the latter only assign a GR to the nominative argument (either actor or undergoer). The dative, by contrast, is directly associated with the LS of the verb, as it does not encode a particular role prototype. This is illustrated in Figure 4.

As Figure 4 shows, linking crucially differs between sentences with accusative verbs and sentences with dative verbs. In the case of accusatives (as in Example 19a), there is a crossed-over linking from the actor-undergoer hierarchy specified by the verb to the linear order of the sentential arguments such that the undergoer precedes the actor (see Figure 2). In dative structures such as in Example 19b, no inverse linking can ensue because only a single GR must be assigned to the argument agreeing with the verb.

The qualitative difference between accusative (as in Example 19a) and dative constructions (as in Example 19b) therefore lies in the distinction of whether the Compute Linking step results in an inverse linking in terms of GRs (thus yielding a P600 effect) and one that entails an assignment of the sole GR to the syntactically less prominent argument (thus yielding an N400 effect). An account along these lines also derives the P600 in Example 14, because this structure clearly calls for an inverse linking despite the fact that only one argument has been processed when the verb is encountered. Here, in combination with the LS of the verb, the existence of an undergoer unambiguously signals that an actor must follow, thereby giving rise to a crossed linking. Furthermore, our interpretation of the N400 in terms of the assignment of a single GR also accounts for the N400-like effect reported by Hopf, Bayer, Bader, and Meng (1998) for the dispreferred resolution of object-object (i.e., accusative-dative) ambiguities. Again, this type of ambiguity involves the reassignment of a single GR and does not result in a crossed linking.

Converging evidence for this interpretation of the reanalysis N400 as a correlate of Compute Linking stems from reanalyses in dative object-experiencer constructions such as

. . . dass Dietmar Sopranistinnen auffallen.

. . . that $\text{Dietmar}_{\text{AMB.SG}}$ $\text{sopranos}_{\text{AMB.PL}}$ $\text{are-striking-to}_{\text{PL}}$

"... that sopranos are striking to Dietmar." (20)

German dative object-experiencer verbs such as *auffallen* ("to be striking to") behave similarly to dative active verbs such as *folgen* ("to be striking to") in Example 19b in that they engender an N400 effect when a reanalysis toward a dative-initial reading is required. However, this effect is less pronounced than that observable for the dative active verbs (Bornkessel, McElree, et al., 2004). The similarity of the components for the two verb types may initially seem surprising because, in contrast to dative active verbs, dative object-experiencer verbs are associated with an unmarked dative-initial word order (e.g., Fanselow, 2000; Haider, 1993; Primus, 1999; Wunderlich, 1997), a theoretically-based assumption that is supported by behavioral studies showing that these verbs do not exhibit the typical disadvantage for object-initial structures (Bornkessel, McElree, et al., 2004b; Schlesewsky & Bornkessel, 2003). This observation thus again attests to the improbability of the negativity versus positivity distinction in reanalysis constellations being attributable to syntactic differences with respect to the target structure.

Rather, the N400 effect for dative object-experiencer verbs may be accounted for in terms of the general properties of dative verbs discussed above, which these verbs share with their active counterparts. Thus, with both classes of dative verbs, the interpretation of the dative argument crucially hinges upon the particular LS of the verb, rather than being derivable from any more general principles governing the linking from form to meaning. The N400 effect for dative verbs therefore appears to derive from the general property that these verbs never entail an inverse linking, because

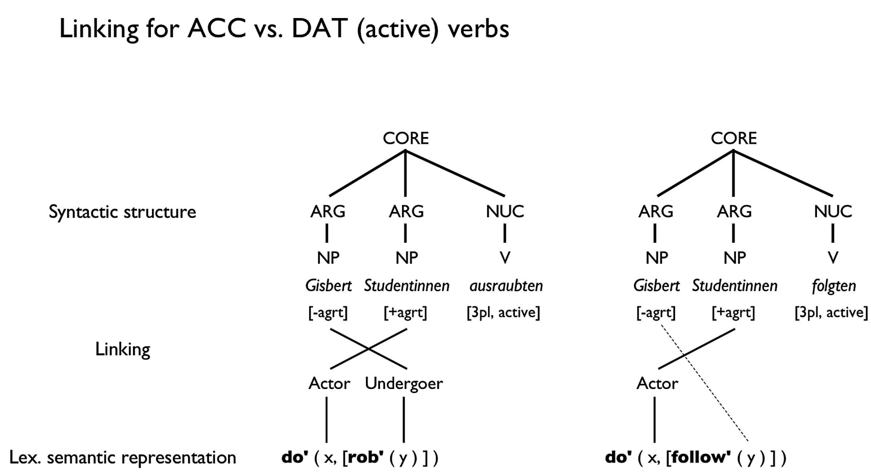

Figure 4. Differences in linking between verbs subcategorizing for accusative (ACC) object case and verbs subcategorizing for dative (DAT) object case in German. Note that only the accusative verbs call for a linking to two GRs, and the dative argument is directly associated with the logical structure of the verb. CORE = the minimal phrase structure domain of the clause within which the nucleus and its arguments are realized; ARG = obligatory argument (noun phrase [NP] or prepositional phrase); NUC = nucleus (essentially equivalent to head, i.e., the element subcategorizing for the arguments); V = verb; arg = argument; agrt = agreement; 3pl. = third person plural; Lex. = lexical.

they can only ever assign a single generalized role. A comparison of the linking for the two dative verb classes is shown in Figure 5.

From Figure 5, it is apparent that the N400 component is independent of whether the single role assigned by a dative verb is that of an actor (as in the case of active verbs) or that of an undergoer (as in the case of object-experiencer verbs). By contrast, which of the two GRs is assigned determines the ease or difficulty of reaching the final interpretation (i.e., as discussed above, the object-initial structure is more acceptable with object-experiencer verbs), because the assignment of the undergoer role to the second argument parallels that argument's position in the verb's LS (see Figure 5). It is this accessibility of the correct object-initial interpretation that is mirrored in the reduced N400 for the disambiguation toward a dative-initial structure via an object-experiencer as opposed to an active verb.

In addition to the effects observed in grammatical function reanalyses, a further correlate of the interaction between ESTABLISH AGREEMENT and COMPUTE LINKING can be observed when there is a principled mismatch between the output of the ESTABLISH AGREEMENT step and another hierarchically ordered input to COMPUTE LINKING (e.g., LS). Such mismatches arise, for example, in constellations in which the +agrt feature must be assigned to the undergoer argument, as in

. . . dass Dietmar Sopranistinnen auffällt.
. . . that Dietmar$_{\text{AMB.SG}}$ sopranos$_{\text{AMB.PL}}$ is-striking-to$_{\text{SG}}$
". . . that Dietmar is striking to sopranos." (21)

At the position of the verb in Example 21, the dative object-experiencer verb leads to a constellation in which the argument agreeing with the verb is the undergoer of the event described by the verb (and thereby the lower-ranking argument in the verb's LS). The COMPUTE LINKING step is therefore rendered more difficult by two mutually incompatible hierarchies (LS vs. +agrt > −agrt). This hierarchy-based mismatch is reflected in a LAN effect (Bornkessel, McElree, et al., 2004). In contrast to the LAN for agreement violations, the LAN for sentences such as in Example 21 is not followed by a late positivity because these sentences are well formed and structurally preferred (see below for a brief discussion of late positivities and their relation to well-formedness requirements).

In summary, the discussion of Phase 2 processing has shown how the requirements imposed by formal (agreement) and interpretive (GR, prominence) relations between core constituents and their interaction can explain (a) how seemingly similar phenomena may give rise to distinct neurophysiological correlates both within and across languages (e.g., grammatical function reanalyses in German; agreement mismatches in German vs. Italian) and (b) why similar neurocognitive processing effects can be observed in different constructions across languages (e.g., early positivities in English, Dutch, and German).

Phase 3

Following the relational processing of core elements performed in Phase 2, Phase 3 is the locus for a GENERAL MAPPING of all available information types, for a WELL-FORMEDNESS evaluation, and for REPAIR steps in the case of a processing conflict.

Generalized Mapping

The GENERALIZED MAPPING step of Phase 3 integrates all available sources of information, both core-internal and core-external. In particular, we assume that factors such as prosody, plausibility/world knowledge, frequency of occurrence and semantic updating do not modulate the processing of core relations in Phase 2 (cf. Bornkessel, 2002; Schlesewsky & Bornkessel, 2004). Rather, the behaviorally observed influences of these factors (e.g., Kempen & Harbusch, 2004; McRae et al., 1997) result from the GENERALIZED MAPPING in Phase 3, in which the outputs of core and noncore

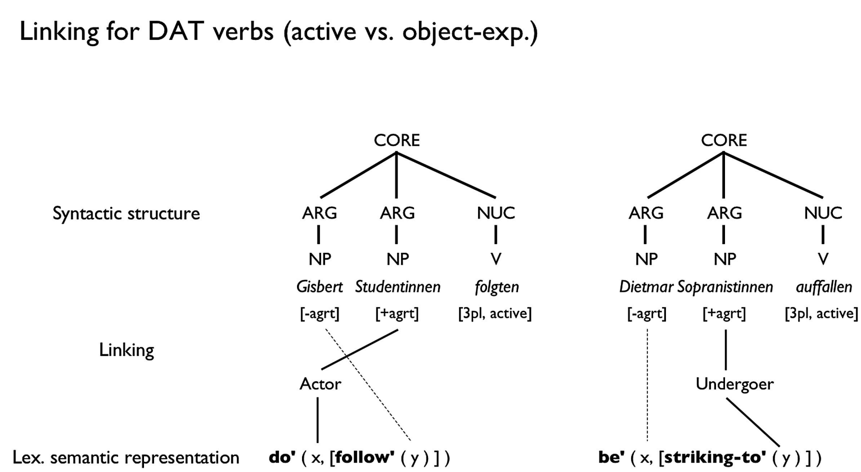

Figure 5. Differences in linking between dative active and dative object-experiencer (exp.) verbs. Whereas both verb classes only assign a single GR (hence the dative case borne by one argument), they differ in that dative active verbs assign the actor role to the nominative argument, whereas dative object-experiencer verbs assign the undergoer role to this argument. The difference between the basic semantic predicates **do′** and **be′** reflects the aspectual distinction between activities and states, a further dimension with respect to which dative active and dative object-experiencer verbs differ.

processing during Phase 2 are integrated with one another. The model thus predicts that these information types should lead to modulations of late positive effects but should not influence Phase 2 components related to the processing of core relations.

Note that, with regard to prosody, matters may be somewhat more complex than for the other information types mentioned above. For example, previous findings indicate that the positioning of intonational phrase boundaries influences properties modeled here in terms of syntactic template selection (Steinhauer, Alter, & Friederici, 1999). Thus, prosodic boundaries may influence processes of template selection in Phase 1 of the subsequent word and might even already have an impact on the processing of the word before the boundary. However, as prosodic boundaries are not informative with respect to the interpretation of an argument (e.g., in terms of GRs), they do not influence the relational aspects of processing in Phase 2. With regard to other prosodic information sources such as pitch modulations, we assume that these do not impact upon argument interpretation before Generalized Mapping because of the inherent relativity of this information (i.e., prosodic prominence of an argument A over an argument B can be determined only by way of a relative comparison between the two arguments). This assumption appears compatible with recent findings regarding the influence of prosody in the processing of subject-object ambiguities in German (Weber, Grice, & Crocker, 2006).

The assumption that core and noncore properties do not interact until Phase 3 should not be taken to imply that the processing of noncore information per se is delayed until Phase 3, but only that there is no interaction between core and noncore properties before this point. Plausibility information, for example, is clearly processed within the Phase 2 time range (as reflected in Kutas and Hillyard's (1980) classical finding of an N400 effect for a plausibility violation) but, in terms of the eADM, does not influence processes such as the assignment of GRs during this time range. This assumption of a separation between core and noncore N400 effects that do not interact with one another is supported by the results of more fine-grained EEG analysis techniques, which have shown that the N400 reflecting lexical-semantic processing shows different underlying characteristics from the N400 correlating with Compute Linking (Roehm, Bornkessel, & Schlesewsky, in press).

As an example for Generalized Mapping, consider the matching process between relative pronouns and their antecedent head nouns that was briefly discussed with respect to Example 18 above. This unification of relative pronoun and head noun features does not qualify as the establishment of a core relation, which by definition involves clause-internal dependencies between arguments or between the arguments and the verb (cf., for example, Van Valin & LaPolla, 1997). Following Frazier and Clifton (1996), this matching process is an instantiation of an associate operation, which (a) displays different properties to operations relating to core constituents and (b) is thought to be a relatively late process. Therefore, we propose that, within the eADM, the crucial relation between the relative pronoun and its head noun is established in the Generalized Mapping step of Phase 3, which also incorporates factors external to the core. Converging evidence for this assumption stems from an experiment reported by Friederici et al. (1998). They examined the processing of relative clauses with unambiguously case-marked relative pronouns such as in

Das ist der Direktor, der . . .
this is [the director]$_{NOM}$ who$_{NOM}$ . . . (22a)

Das ist der Direktor, den . . .
this is [the director]$_{NOM}$ who$_{ACC}$ . . . (22a)

Crucially, the relative clauses in Example 22 both modify a nominative-marked actor in the matrix clause. As predicted by the model's assumptions regarding the late GR-matching process, Friederici et al. (1998) observed a late positivity for the accusative relative pronoun *den* in Example 22b, in comparison with the nominative relative pronoun in Example 22a. This strongly supports the idea that the matching process takes place in the Generalized Mapping step of Phase 3, rather than in Phase 2. Further findings show that this late effect must indeed be attributed to the specific properties of relative pronouns, because unambiguously case-marked *wh*-pronouns in indirect questions do not show an analogous effect, despite the fact that they share all core-related properties of relative pronouns (Fiebach, Schlesewsky, & Friederici, 2002).

Two further examples for Generalized Mapping can be found in the ERP literature on English. The first of these was originally discussed in Example 4 (from Osterhout & Holcomb, 1992, 1993) in relation to Phase 1 processing and is repeated here.

The broker persuaded to sell the stock was sent to jail. (23a)

*The broker hoped to sell the stock was sent to jail. (23b)

The first effect observed in the comparison of Examples 23a and 23b was a late positivity at the position of (the first occurrence of) *to* in Example 23a, where it becomes apparent that the sentence includes a reduced relative clause. Thus, in Phase 1, *to* cannot be integrated into the main clause template and thus leads to a template combination step (reduced relative clause template inserted). No problems arise in Phase 2, because the infinitival marker *to* contains neither agreement information nor a LS from which a computation of linking properties could be initiated. Finally, when the Generalized Mapping step is reached in Phase 3, the reduced relative clause template indicates that the first argument must bear the undergoer role within the reduced relative clause, thus contradicting the previous actor assignment. This mismatch in Generalized Mapping results in a late positivity, which is fully analogous to the effect observed for unambiguously case-marked object-relative pronouns in Example 22 (Friederici et al., 1998).

In contrast to the positivity at the position of *to*, the late positive effect elicited by *was* in Example 23b is a reflection of the Well-Formedness check subsequent to Generalized Mapping. As discussed in the section on Phase 1, the analysis of Example 23b fails at the position of *was* because of a template selection failure. This leads to a reduction in well-formedness and, possibly, to the initiation of Repair processes.

The Generalized Mapping step also accounts for the late positivity observed by Kaan, Harris, Gibson, and Holcomb (2000) in response to increased integration difficulty between a verb and one of its arguments. Specifically, this effect was observable at the position of *imitated* in Example 24a in comparison with Example 24b.

Emily wondered who the performer in the concert had imitated for the audience's amusement. (24a)

Emily wondered whether the performer in the concert had imitated a popstar for the audience's amusement. (24b)

At the position of *imitated* in Example 24a, there is no problem in Phase 2 of processing, because the COMPUTE LINKING step confirms the previous GR assignments (carried out via the positional information of the embedded object *wh*-question). Beyond the processing of these abstract interpretive properties, however, the verb must also be integrated with the full semantic representations of its arguments, a step which takes place during GENERALIZED MAPPING within the eADM. Here, then, additional factors such as working memory costs come into play, thus leading to a higher integration difficulty for Example 24a than Example 24b. This assumption is further supported by the observation that a third condition with an embedded object question involving a *which*-phrase led to an even more pronounced positivity at the position of the embedded verb than Example 24a, because here the semantic information associated with an entire NP had to be maintained.

Well-Formedness/Repair

With respect to the late positivities observed for the processing of ill-formed structures in a variety of languages, we assume that these are a reflection of the WELL-FORMEDNESS evaluation/REPAIR steps in Phase 3 (e.g., de Vincenzi et al., 2003; Hagoort, Brown, & Groothusen, 1993; Kaan & Swaab, 2003; Neville et al., 1991; Osterhout & Holcomb, 1992, 1993; Rösler, Friederici, Pütz, & Hahne, 1993, among many others). Thus, these effects are functionally distinct from the P600 components for the reanalysis of grammatical functions, which as discussed extensively above, are most plausibly accounted for in terms of the COMPUTE LINKING step of Phase 2b. Although the empirical foundations for this model-theoretic separation between the two effects require further systematic investigation, the proposed dissociation between the P600 and the late positivity is supported by several independent pieces of evidence. First, neuroanatomical findings support a distinction between the processing of sentences involving a violation and sentences with a dispreferred structure (Friederici, 2004, and see below). Furthermore, a number of researchers have argued that late positive effects should be interpreted as reflecting more general processes related to the evaluation of well-formedness, rather than, for example, to an increased syntactic processing effort. For example, Gunter, Stowe, and Mulder (1997, Experiment 2) observed a modulation of a late positivity in response to a semantic manipulation, thus leading them to argue for an association between this effect and general evaluative processes in the sense described above.[7] In addition, Steinhauer, Mecklinger, Friederici, and Meyer (1997) observed that late positivities can be modulated by experiment-internal manipulations relating to the probability of occurrence of structures with a degraded acceptability (cf. also Hahne, 1998). Finally, Roehm (2004) reports a biphasic N400-late positivity pattern for the processing of sentences such as *The opposite of black is nice*, in which the prediction of an antonym is not fulfilled. Here, too, there is no syntactic processing problem whatsoever, so that the late positive effect appears to result from a global evaluation of the sentence's well-formedness.

Interaction of Generalized Mapping and Well-Formedness Check

A study that nicely illustrates the relationship between the GENERALIZED MAPPING and WELL-FORMEDNESS/REPAIR steps in Phase 3 was reported by Kaan and Swaab (2003). They compared the processing of grammatical but dispreferred structures (e.g., see Example 25b) to that of ungrammatical sentences (e.g., see Example 25c).

I cut the cake beside the pizzas that were brought by Jill. (25a)

I cut the cakes beside the pizza that were brought by Jill. (25b)

*I cut the cake beside the pizza that were brought by Jill. (25c)

Example 25b is a case of a dispreferred (high) relative clause attachment; that is, the relative clause *that were brought by Jill* must be attached to *cakes* via number agreement, rather than to the preferred low attachment site, *pizza* (as in Example 25a). By contrast, there is no possibility for a well-formed attachment in Example 25c, because both possible head nouns are singular, while the auxiliary in the relative clause is plural. As described above, the relation between a relative clause and its head noun is a secondary (noncore) relation (Frazier & Clifton, 1996). The number mismatch between the head noun and the relative clause auxiliary is therefore not expected to lead to a LAN as the result of a processing conflict in Phase 2 (see Example 14), a prediction that is also borne out in the data. Rather, for both Examples 25b and 25c, Kaan and Swaab (2003) observed late positive effects, which differed, however, with respect to both amplitude and topographical distribution such that the positivity for Example 25c was more pronounced than that for Example 25b and also somewhat more posterior. Within the eADM, both Examples 25b and 25c lead to a processing conflict within the GENERALIZED MAPPING step of Phase 3, when core-external information is mapped onto the output of Phase 2 processing. Here, the presumed low attachment is not compatible with the morphological features of the relative clause auxiliary, thereby engendering increased processing cost. In addition, Example 25c involves a WELL-FORMEDNESS problem. As predicted by the model, the combination of two Phase 3-based processing problems leads to a more pronounced late positive effect, which presumably reflects the summation of the GENERALIZED MAPPING and WELL-FORMEDNESS/ REPAIR steps.

More generally, the contrast between the two effects found by Kaan and Swaab (2003) also points to one of the open questions presently remaining with regard to Phase 3. Although, as discussed above, we assume that all processing difficulties in Phase 3 are reflected in late positive effects, the fine-grained differences between the distinct processing steps assumed within this phase and

[7] Kim and Osterhout (2005) also observed a (seemingly monophasic) late positivity in response to a semantic incongruency (e.g., in *The hearty meal was devouring . . .*). However, visual inspection across the different figures presented (both within and across experiments) in fact reveals a biphasic N400-P600 pattern, that is, an N400 for both the semantically incongruent condition as well as for its active control. Thus, the data appear to call for a similar interpretation as Gunter et al.'s (1997) findings, namely as showing an influence of semantic/plausibility information on the WELL-FORMEDNESS check in Phase 3.

their neurocognitive correlates require further specification. The topographical differences reported by Kaan and Swaab (2003) appear to be a promising first step in the direction of such a dissociation (cf. also Friederici, Hahne, & Saddy, 2002). Similarly, the current formulation of the model strongly predicts empirical correlates of the proposed distinction between the linking-related positivities in Phase 2b and the late positive effects in Phase 3 of processing. One expected consequence of this subdivision is that the latter may be related to the P300 family (see Picton, 1993, for an overview), hence reflecting more general (e.g., task-related) processes within higher cognition.

A Note on the Correlation Between ERP Components and Individual Processing Steps

In the discussion of the eADM's neurophysiological correlates, the reader will have noted that the association between ERP components and individual processing steps appears relatively complex. Thus, there is no one-to-one mapping between components and boxes in Figure 1. Most generally, this reflects the fact that the idea of a direct association between particular ERP components and specific cognitive mechanisms—which long fueled the hopes of psycholinguists—cannot be upheld (for discussion, see Kutas, Van Petten, & Kluender, in press; Roehm et al., 2004). The absence of a such a direct correlation is not unexpected given the neurophysiological foundations of the experimental method in question: It is well known that the same surface component can be generated by different underlying sources (the well-known inverse problem; e.g., Nunez, 1981).

Nonetheless, as we outline in the following, this does not mean that the distribution of components within the model architecture is arbitrary. In particular, we discuss (a) why there are similar components for COMPUTE PROMINENCE (NP processing) and COMPUTE LINKING (V processing) within Phase 2 of the model and (b) how different components within the same box can be interpreted. Finally, we briefly turn to some more general considerations regarding the functional interpretation of ERP components.

First, consider the observation that within Phase 2 of processing, the component patterns for NP processing and verb processing appear to mirror one another. Thus, LAN effects are apparent for agreement mismatches in both processing pathways and for hierarchy mismatches in the COMPUTE LINKING step. As we have argued that an agreement problem that engenders a LAN can be viewed as a special case of a hierarchy mismatch (see the section *The interaction between establish agreement and compute linking*), the functional interpretation of this component remains uniform despite the fact that it is associated with several different boxes within the model. A similar situation arises for the COMPUTE PROMINENCE and COMPUTE LINKING steps: Both are associated with N400 and P600 effects. Again, this is no accident. Within the theoretical assumptions of the model, COMPUTE PROMINENCE is to nouns essentially what COMPUTE LINKING is to verbs. Thus, in the former case, arguments are ranked with respect to one another on the basis of their inherent properties (e.g., case and animacy), whereas the latter involves a similar hierarchization via properties of the arguments and the verb (agreement, voice, LS). The correspondence between components and processing mechanisms within the different parts of Phase 2 is thus rather parsimonious.

Despite this similarity between the COMPUTE PROMINENCE and COMPUTE LINKING steps, however, we see good reasons to represent the two separately within the model architecture. On the one hand, the relative ordering between these steps and the processing of agreement information is reversed between NPs and verbs. This stems from the fact that the agreement status of arguments is derived from their relative degree of prominence, whereas when a verb is encountered, the establishment of an agreement relation(s) is the formal prerequisite for the linking to a semantic interpretation. The second motivation for assuming separate computations of prominence and linking is neuroanatomical in nature. As we outline in the section *Neuroanatomical Correlates*, the two processing steps are correlated with distinct subregions within a larger network for the processing of verb-argument relations (see the section on the neuroanatomical correlates of Phase 2). Thus, the N400 and P600 effects arising in each case are associated with a similar fronto-temporal (+ basal ganglia) network, with the activation of the network's subregions modulated differentially for NP as opposed to verb processing.

This leads us directly to the second pattern described above, namely the appearance of several components within the same model box. In essence, several components may coexist as a result of different types of input information feeding into a particular processing step. In the case of COMPUTE PROMINENCE, for example, an N400 indexes increased processing cost arising from the relation between the prominence features of the current argument and those of previously processed arguments. The scrambling negativity, by contrast, is observable when the prominence information of an argument is incompatible with the current template. We therefore see two components related to the processing of (argument-related) prominence information in Phase 2 (hence one box), but arising from two functionally different input information types (hence two components).

These observations attest to a systematic distribution of ERP components within the architecture of the eADM. ERP effects can therefore be predicted given a precise characterisation of input properties in combination with the features of the element currently being processed (see the section Cross-Linguistic Predictions, below).

Neuroanatomical Correlates

The neurophysiological foundations of the eADM's processing architecture are complemented by findings on the functional neuroanatomy of core relation processing. Note that the intention of this section is not to provide a specific localization of individual processing steps assumed within the model, but rather to provide a first indication of which component parts of the overall language network can be shown to correlate with particular aspects of the processing architecture. Again, we discuss the model's three phases in turn.

Phase 1

Studies examining the neuroanatomical bases of language processing have also revealed evidence for the assumption of a distinct role for word category-based minimal constituent structuring. In particular, the findings of functional imaging and electrophysiological patient studies employing similar paradigms to those discussed above suggest that the anterior portion of the superior temporal gyrus may be crucially involved in the establishment of local syntactic relations (Friederici & Kotz, 2003; Friederici, Rüschemeyer, Fiebach, & Hahne, 2003). Supporting evidence for this assumption stems from deficit–lesion correlations (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004). A further neuroanatomical correlate of Phase 1 processing has been observed in the left posterior deep frontal operculum (Friederici, Fiebach, Schlesewsky, Bornkessel, & von Cramon, in press; Friederici et al., 2003). In particular, Friederici et al. (in press) observed a double dissociation between activation in the deep frontal operculum for processing conflicts attributable to template selection failure (illegal constituent order) and activation in the pars opercularis of the left inferior frontal gyrus (IFG) for increased processing cost attributable to a more complex linking (argument permutation). These findings thus support the assumed independence of phrase structure information (syntactic templates) in Phase 1 and argument interpretation/linking in Phase 2 (for an in-depth discussion see Bornkessel & Schlesewsky, 2006).

Phase 2

Of the relational processes assumed to take place in Phase 2b of the eADM, word order variations are best examined in terms of their neuronal correlates. Thus, a number of researchers have examined the comprehension of object-initial structures using functional imaging. As discussed in the introduction, these experiments have yielded intriguing cross-linguistic differences with regard to the cortical regions involved in the processing of seemingly comparable sentence types. Consider Examples 26 (from Stromswold et al., 1996) and 27 (from Fiebach, Vos, & Friederici, 2004).

The child spilled the juice that stained the rug. (26a)

The juice that the child spilled stained the rug. (26b)

Das sind die Einwohner, die den Polizisten angehört haben.

these are the citizens who [the policeman]$_{ACC}$ listened-to have.

'These are the citizens who listened to the policeman.' (27a)

Das sind die Einwohner, die der Polizist angehört hat.

these are the citizens who [the policeman]$_{NOM}$ listened-to has.

'These are the citizens to whom the policeman listened.' (27b)

Both the English Example 26b and the German Example 27b include object-relative clauses (marked in italics), whereas Examples 26a and 27a each contain a subject-relative clause. Thus, in Examples 26b and 27b, the object linearly precedes the subject, occupying the sentence-initial position because of a rule for relative-clause formation (i.e., relative pronouns must precede all other material in the relative clause) that applies in both English and German. Nonetheless, only English object relatives have been associated with an activation increase in the pars opercularis of the left IFG, that is, a core subregion of Broca's area, in comparison to their subject-initial counterparts (e.g., Caplan et al., 2000; Constable et al., 2004; Just et al., 1996; Keller et al., 2001; Stromswold et al., 1996).[8] By contrast, pars opercularis activation has not been observed for object relative clauses in German (Fiebach, Vos, & Friederici, 2004), nor for structurally similar object *wh*-questions (Fiebach et al., 2005). Note that these differences cannot be attributed to the local ambiguity of case marking in the German examples used by Fiebach, Vos, and Friederici (2004; see Bornkessel et al., 2005).

Rather, only the permutation of arguments in the medial portion of the German clause ("scrambling") leads to increased pars opercularis activation in German (Friederici et al., in press; Röder et al., 2002). This type of word order variation is generally described as having different properties to the clause-initial positioning of an object in relative clauses or *wh*-questions (e.g., Haider & Rosengren, 2003). An example is given in below (from Röder et al., 2002).

Jetzt wird dem Forscher der Astronaut den Mond beschreiben.

now will [the scientist]$_{DAT}$ [the astronaut]$_{NOM}$ [the moon]$_{ACC}$ describe

"Now the astronaut will describe the moon to the scientist." (28)

Similar to the relative clauses above, Example 28 involves an argument order in which an object precedes a subject. However, the permutation is clause medial, rather than targeting the clause-initial position. In this way, the example also illustrates a further important property of German, namely that only the medial section of the clause (the so-called "middlefield") directly encodes prominence relations (e.g., actor > undergoer, animate > inanimate) in terms of linear precedence (cf. the discussion of the COMPUTE PROMINENCE step in the section on neurophysiological foundations). By contrast, the clause-initial position (also known as the "prefield") has the distinguishing property that it can host any single constituent independently of that constituent's category or grammatical function. This position can, for example, be occupied by nonsubject constituents (such as the adverb *jetzt* in Example 28) even in fully unmarked sentences. It therefore appears that, during sentence comprehension, the processing system does not endeavor to map constituents occupying this clause-initial position to hierarchical prominence relations in the same way as constituents in the middlefield. In this way, contrasts between subject- and object-relative clauses and *wh*-questions—in which the relative pronouns and *wh*-constituents always occupy this sentence-initial position—fail to yield reliable pars opercularis activation. In languages such as English, by contrast, linearization principles are much more restrictive, such that the COMPUTE PROMINENCE step always expects a direct match between the GR hierarchy and the linear argument order. Therefore, objects preceding subjects are always mapped onto an inverse hierarchy and therefore always give rise to increased pars opercularis activation.

The crucial difference between German and English therefore lies in the representations that are integrated with the current GR information in the COMPUTE PROMINENCE step, that is, in the representations that are crucial for determining hierarchy-based predictions. Thus, whereas the expectations with regard to the map-

[8] Readers familiar with the fMRI literature on word order processing will be aware that a small number of studies comparing subject and object relative clauses in English have failed to find activation differences in Broca's region. However, the absence of an effect in these experiments is likely attributable to other factors that interacted with the intended complexity manipulation, for example (in Caplan et al., 2001), to material intervening between the head noun and the relative clause.

ping between surface order and argument interpretation differ depending on the position within the clause in German (clause-initial vs. clause-medial), they are invariant in English, thereby always calling for a subject-before-object order. Converging evidence for this claim stems from Ben-Shachar and colleagues' (Ben-Shachar, Hendler, Kahn, Ben-Bashat, & Grodzinsky, 2003; Ben-Shachar, Palti, & Grodzinsky, 2004) finding of increased pars opercularis activation for object topicalization in Hebrew, for Example 29b versus 29a, for instance:

Control

John natan ['et ha-sefer ha-'adom]$_1$ [la-professor me-oxford]$_2$

John gave [ACC the-book the −red] [to-the-professor from-Oxford] (29a)

Topicalization

['et ha-sefer ha-'adom]$_1$ John natan [la-professor me-oxford]$_2$

[ACC the-book the −red] John gave [to-the-professor from-Oxford] (29b)

Although Hebrew is similar to German in that it has morphological case marking and allows a flexible word order, it is similar to English (and Finnish) in showing left-adjacency constraints between subject and verb. Thus, the first argument position in the sentence is informative with respect to argument prominence (GR assignments), and OSV sentences lead to increased pars opercularis activation.

One important function of the pars opercularis cross-linguistically therefore appears to lie in decoding the prominence relations between arguments. To this end, the correspondence between linear order information (in possible core argument positions, see above) and inherent prominence features of the arguments is evaluated. From this perspective, the increased pars opercularis activation for sentences with an object-before-subject order may be considered an epiphenomenon of the distribution of prominence features (i.e., subjects are typically higher in prominence along all relevant dimensions than objects). Converging support for such a view stems from recent findings showing that object-initial sentences do not engender increased pars opercularis activation in comparison with their subject-initial counterparts when object and subject are equally prominent or the object even outranks the subject in terms of prominence. This was shown using GR information in Bornkessel et al. (2005), using pronouns versus nonpronominal arguments in Grewe et al. (2005) and by means of an animacy contrast in Grewe et al. (in press).

This account of pars opercularis function during sentence comprehension appears at least partially compatible with more general approaches to the role of this area in higher cognition. For example, Thompson-Schill and colleagues (Thompson-Schill, Bedny, & Goldberg, 2005; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997) have suggested that Broca's region is crucially involved in the selection of a critical representation among a set of competitors. Indeed, it has been suggested that this type of mechanism can also potentially account for nonlinguistic effects of relational complexity observed in the left inferior frontal gyrus (Kroger et al., 2002). The use of different information types to establish argument prominence may thus constitute a special case of selection in this sense.

As discussed in the section on the correspondence between neurophysiological components and processing steps, the COMPUTE PROMINENCE step for arguments shares a close functional association with the COMPUTE LINKING step. However, the two processing steps differ (a) with respect to their order of application relative to agreement processing and (b) in that only COMPUTE LINKING serves to bind together argument properties and properties of the verb/clause, because this step establishes a correspondence between the inherent prominence features of the arguments, their formal status (in terms of agreement), and the semantic representation of the verb (its LS) using global features of the clause such as voice. These functional distinctions between COMPUTE PROMINENCE and COMPUTE LINKING are mirrored in neuroanatomical terms: In contrast to COMPUTE PROMINENCE, COMPUTE LINKING may be associated with left posterior superior temporal regions, particularly with the posterior portion of the left superior temporal sulcus (STS; Bornkessel et al., 2005). Thus, the posterior STS appears to engage in the mapping of arguments/argument hierarchies onto the LS of the verb, thereby leading to a dominance of LS-based information (rather than prominence information) in the resulting activation patterns (Bornkessel et al., 2005).

From a broader perspective, the association between the posterior STS and an integration of verb and argument-based information can be couched within a more general account of this region's function during cognitive processing. Thus, this region has been implicated in the integration of a wide range of information types during language processing (Scott & Johnsrude, 2003) and in cross-modal information processing both in language (Sekiyama, Kanno, Miura, & Sugita, 2003; Wright, Pelphrey, Allison, McKeown, & McCarthy, 2003) and with respect to more general sources of information (Calvert, 2001). Furthermore, the role of the posterior STS in linking between form and meaning also appears appealing in view of this region's more general role in the inference of agency (cf. C. D. Frith & Frith, 1999; U. Frith & Frith, 2003).

In summary, the neuroanatomical processing correlates described in this section consistently support the eADM's characterization of Phase 2 of processing. There is converging evidence not only for the role of prominence features in argument processing, but also for the separability of the COMPUTE PROMINENCE and COMPUTE LINKING steps in neuroanatomical terms. The model's predictions are therefore consistently borne out in both the temporal and spatial domains and provide a new conceptualization of how these two domains converge during the real time processing of core constituents.

Phase 3

The neuroanatomical bases for processes relating to the eADM's Phase 3 are difficult to isolate because of the relative temporal insensitivity of neuroimaging methods such as fMRI. Thus, because many of the manipulations leading to Phase 3 effects also engender increased processing costs in earlier phases, it is often difficult to dissociate the specific components within the complete network engaging in the comprehension of the sentences in question. However, there are several tentative indications as to the network involved in Phase 3 processes. With respect to the GENERALIZED MAPPING step, it has been suggested that the posterior portion of the left superior temporal gyrus may play a crucial role in mediating the interaction between syntactic and semantic properties, as this region shows increased activation in response to both

Table 2
Summary of the Extended Argument Dependency Model's Neuroanatomical Correlates

Processing step	Anatomical region	Language	Example	Reference
Phase 1				
Template activation/selection	Anterior STG, posterior deep frontal operculum	German		Friederici et al. (2003); Friederici and Kotz (2003)
Phase 2				
Compute prominence	Pars opercularis of IFG	English, German, Hebrew	26, 28, 29	Bornkessel et al. (2005); Grewe et al. (2005); Grewe et al. (in press)
Establish agreement (mismatch with GR information) compute linking	Pars opercularis of IFG Posterior STS	English German		Newman et al. (2003) Bornkessel et al. (2005)
Phase 3				
Generalized mapping well-formedness/repair	Posterior STG Deep frontal operculum/ basal ganglia	German German		Friederici et al. (2003) Friederici et al. (2003); Frisch et al. (2003); Grewe et al. (2005)

Note. STG = superior temporal gyrus; IFG = inferior temporal gyrus; GR = generalized semantic roles; STS = superior temporal sulcus.

syntactic (phrase structure) and semantic (selectional restriction) violations (Friederici et al., 2003). As for possible neural correlates of the WELL-FORMEDNESS assessment in Phase 3, recall from the discussion of Phase 1 above that a number of studies examining syntactic violations have yielded increased activation in the deep frontal operculum. Of interest is that this region's involvement is also modulated by the experimental task, with grammaticality/acceptability judgements more likely to lead to fronto-opercular activation in sentences with a degraded acceptability (Grewe et al., 2005). In addition, WELL-FORMEDNESS/REPAIR processes may be supported by the basal ganglia, as indicated by both ERP studies with patients (Frisch, Kotz, von Cramon, & Friederici, 2003) and fMRI studies using violation paradigms (Friederici et al., 2003).

Summary: Neuroanatomical Correlates

The neuroanatomical correlates of the processing steps assumed within the eADM are summarized in Table 2. In contrast to the summary of the model's neurophysiological correlates in Table 1, Table 2 also cites the relevant references from the literature when no explicit examples were given in the text.

Clearly, fewer studies speak to the neuroanatomical foundations of the model as opposed to its neurophysiological bases. Nonetheless, the present data pattern clearly motivates the individual processing steps discussed and shows how their cross-linguistic similarities and differences may be envisaged.

Cross-Linguistic Predictions

In its present form, the eADM generates a number of cross-linguistic predictions, which require testing in future experiments. Most fundamentally, these predictions are based upon the assumption that similar processing steps (i.e., identical boxes + input properties in Figure 1) should lead to similar effects across languages, while the information types drawn upon by these specific mechanisms may be expected to differ from language to language. For example, additional costs arising from a mismatch with previously computed prominence information within the COMPUTE PROMINENCE step engender an N400 both in English (Weckerly & Kutas, 1999) and German (Frisch & Schlesewsky, 2001), but these crucially involve positional information in the former and morphological information in the latter.

How, then, can predictions for a particular language be derived within the eADM-framework? Because we assume that the main locus of cross-linguistic variation is situated within Phase 2 of processing, the following properties serve as a point of departure with respect to the derivation of predictions:

1. Does the language under consideration have morphological marking?

(a) Case marking of arguments is generally predicted to have consequences for prominence assignment.[9]

(b) Morphological informativity (i.e., to which degree case marking is unambiguous) influences the potential activation of prominence hierarchies via case. However, not all ambiguities are equal (e.g., an ambiguity between core cases such as nominative and accusative is predicted to show a much stronger effect than an ambiguity between a core case and an oblique case, e.g., between accusative and instrumental, as a result of a preference for core elements).

2. Does the language under consideration show positional restrictions?

(a) An unrestricted relative ordering of the arguments with respect to one another is predicted to lead to morphology-based prominence

[9] We refrain from discussing "head-marking" languages, that is, languages in which, in contrast to case marking on the arguments ("dependent marking"), the relation between arguments and verbs is encoded morphologically on the verb rather than the arguments (Nichols, 1986). Examples of head-marking languages are Navajo, Lakhota, Tzotzil and Abkhaz (NW Caucasian). While we believe that the model has the capacity to capture processing behavior in head-marking languages (e.g., via the interaction of ESTABLISH AGREEMENT and COMPUTE LINKING), the complete absence of psycholinguistic investigations for these languages in comprehension would render any proposed account unnecessarily speculative.

assignments if the language in question has morphological marking (if not, position-based assignments are predicted nonetheless as a last-resort strategy)

(b) By contrast, adjacency restrictions between arguments and verbs lead to position-based prominence assignments even in languages with morphological marking (e.g., Finnish, Hebrew).

(c) Similarly, for languages with a rigid word order in combination with morphological marking, position is expected to be informative with respect to prominence assignments within the range of possibilities delineated by the morphology (e.g., initial dative arguments in Icelandic are analyzed as subjects).

3. Does the language under consideration allow argument drop?

(a) A strong tendency towards argument drop has consequences for the interaction between template structure and linking regularities. Thus, in a language with a high proportion of dropped subjects (e.g., Turkish, Japanese), an initial accusative argument is compatible with a phrase structure template containing only a single argument position (we assume no empty categories).

4. Does the language under consideration have agreement?

(a) A language with agreement between at least one argument and the verb and in which the agreeing argument must be realised overtly, agreement is predicted to determine the outcome of the COMPUTE LINKING step (e.g., Russian). This is a consequence of the relative hierarchical ordering between ESTABLISH AGREEMENT and COMPUTE LINKING in Phase 2b for predicating elements.

5. Which prominence hierarchies play a role in the language under consideration?

(a) As outlined in several places throughout this article, prominence information can be derived from a number of different hierarchies. The typological literature suggests that the relevant information types (besides case, position, and GRs) are animacy, definiteness/specificity, person (e.g., first and second person vs. third person), referential status (i.e., pronouns vs. nonpronominal arguments), and possibly topicality.

(b) Prominence hierarchies that are applicable in a particular language should determine the outcome of prominence computation. The applicability of a hierarchy is apparent, for example, if that hierarchy serves as a determinant of (a) word order preferences, (b) morphological encoding of arguments (e.g., only specific objects are marked with accusative case in Turkish), or (c) GR assignments (see the discussion of the Fore Example 2).

In the following, we illustrate the way in which these properties can be used to derive concrete predictions on the basis of three examples. The first of these concerns argument processing, and specifically the COMPUTE PROMINENCE processing step, whereas the second and third are taken from the domain of verb processing and relate to COMPUTE LINKING.

Compute Prominence (Scrambling Negativity)

As discussed in the section on the neurophysiological correlates of argument processing in Phase 2, the COMPUTE PROMINENCE step engenders a fronto-central negativity between approximately 300 and 500 ms post critical word onset (the so-called "scrambling negativity") when the case marking of an initial argument in the medial portion of the German clause is not compatible with the currently active intransitive (one-argument) phrase structure template. Should this effect therefore be expected to appear in all languages with morphological case marking in which an object can be scrambled to a position in front of the subject?

The model clearly predicts that the answer to this question should be "no." Rather, whether a scrambling negativity is expected depends crucially upon whether the language under consideration allows argument drop. If so, as indicated in the general prediction section above, an initial argument that is clearly marked as an object is nonetheless compatible with an intransitive phrase structure template (seeing that we do not assume any empty categories such as *pro*). Languages such as Japanese and Turkish, which are of this type, should therefore not be expected to show a scrambling negativity despite the fact that both languages undisputedly allow scrambling. For Japanese, this prediction indeed appears to be borne out, as Ueno and Kluender (2003) observed no negativity for scrambled arguments in declarative sentences. Rather, Ueno and Kluender observed a late positivity at the position of the scrambled argument, which we would clearly attribute to Phase 3 of processing. By contrast, for scrambling languages without argument drop (e.g., Russian), we expected to observe a scrambling negativity similar to that found in German.

Compute Linking I (Early Positivities)

Recall that we have identified an early (approximately 200–600 ms) parietal positivity as a correlate of the COMPUTE LINKING step, which is observable whenever previously assigned GRs are not compatible with the properties of the current input item. This leads to clear predictions, which we illustrate on the basis of Icelandic. As this language has strict word order constraints, the first argument will always be interpreted as the argument with the highest GR independently of its case marking. In addition, Icelandic (like German) is a language with true object-experiencer verbs (i.e., verbs in which the dative object is associated with a higher position in the verb's LS than the nominative subject). The eADM therefore predicts that, when an initial nominative argument is followed by an object-experiencer verb in Icelandic, an early positivity should result.

Compute Linking II (LAN Effects and the Role of Agreement)

As is apparent from Figure 1, the model assumes two distinct LAN effects as correlates of verb processing in Phase 2b. One of these arises when ESTABLISH AGREEMENT conflicts with previous GR assignments (the "agreement LAN"), and the other is observable when there is a principled mismatch between the argument hierarchy in the verb's LS and the agreement hierarchy (the "linking LAN"). Whereas the agreement LAN is relatively well established in a number of languages, the linking LAN has hitherto been observed only in German. Indeed, we believe that instances of the linking LAN may be quite rare because they arise only when there is no problem with the input to the COMPUTE LINKING step (i.e., when there is neither an agreement mismatch nor a conflict with respect to previous GR assignments). However, such effects are predicted to occur in languages other than German when these preconditions are fulfilled.

A case in point is Hindi. In this language, case marking either adheres to a nominative-accusative or to an ergative-absolutive alignment system, depending on aspect (i.e, ergative-absolutive alignment for perfective aspect and nominative-accusative alignment elsewhere).[10] As the language is verb final, aspect is only disambiguated at the end of the clause. In addition, Hindi shows gender agreement between unmarked (nominative/absolutive) arguments and the verb. Under these circumstances, we expect to observe a linking LAN when the case marking pattern of the arguments is not compatible with the aspect of the verb (e.g., when a clause containing an ergative argument is disambiguated towards imperfective aspect in the clause-final position). Here, there is a conflict between the GR hierarchy (as assigned via case) and the argument hierarchy specified by agreement/aspect. Whereas the former calls for an assignment of the highest GR to the ergative, the latter specifies that it is the absolutive (which agrees with the verb) that should receive the highest-ranking GR. This illustrates one of the main properties that must be dealt with in the comprehension of ergative languages: ergative case marking on an argument unambiguously calls for an assignment of the actor role (similar to accusative case marking calling for the assignment of the undergoer role in nominative-accusative languages). Thus, the processing of prominence information may be envisaged to proceed in a similar manner in the two language types, albeit with different mapping parameters governing the association between case and GRs.

In addition, Hindi presents us with the opportunity to contrast the linking LAN with the agreement LAN. Because a gender mismatch between a nominative/absolutive argument and the verb should lead to a typical instance of an agreement LAN, we can directly compare this effect with the linking LAN discussed above at an identical position in the sentence. Such a direct comparison would clearly help to shed further light on the question of whether the two LAN effects for ESTABLISH AGREEMENT and COMPUTE LINKING can also be differentiated from one another in neurophysiological terms (e.g., on the basis of slightly different topographical distributions, latencies, or underlying frequency characteristics).

Compute Prominence Versus Compute Linking (Pars Opercularis of the Left IFG vs. Left Posterior STS)

In the section on neuroanatomical correlates of Phase 2, we outlined the division of labor between the COMPUTE PROMINENCE and COMPUTE LINKING processing steps. Because of the cross-linguistic differences with respect to which properties are involved in linking proper, we should therefore also expect to observe differences with respect to the modulation of inferior frontal as opposed to posterior superior temporal activation depending on the language in question. A case in point is animacy: Although this feature plays an important role in determining argument prominence, this does not necessarily render it informative with respect to (verb-based) argument linking proper. Thus, animacy distinctions between the arguments in a language such as German lead to modulations of pars opercularis activation (Grewe et al., in press) because animacy only affects the prominence relations established between the arguments themselves. At the position of the verb, however, animacy is not used to determine the linking to the final interpretation; hence, no modulation of posterior STS activation is observable. By contrast, for a language in which animacy plays an integral role in linking to the verb's LS (e.g., Fore), animacy variations between the arguments should clearly manifest themselves in modulations of left posterior STS activation.

In summary, the present formulation of the eADM leads to a wide range of testable predictions, of which we have outlined only a selection. Testing these hypotheses in future research constitutes an important goal in furthering our understanding of the neurocognitive bases of language comprehension and their cross-linguistic similarities and differences.

Beyond Phase 3: The eADM and Behavioral Measures

As the eADM is a neurocognitive model of language comprehension, our main focus clearly lies in deriving the neurophysiological and neuroanatomical correlates of processing described above. Nonetheless, the question arises of how the model relates to nonneurophysiological, behavioral findings. Although it appears legitimate to assume that all processing effects observable with behavioral methods should be somehow mirrored in neurophysiological/neuroanatomical data, the opposite expectation, namely that each neurophysiological/neuroanatomical effect should also be associated with behavioral correlates, appears less well founded (cf., for example, Bornkessel, McElree, et al., 2004). For example, the precise source of longer reaction times or higher error rates correlating with a biphasic ERP pattern is impossible to determine because of the unidimensionality of most behavioral measures. Nonetheless, there do seem to be correspondences between the processing patterns discussed above and behavioral findings. We illustrate these on the basis of three examples, to provide a first indication of how the model can be integrated with behavioral data.

Speed–Accuracy Tradeoff (SAT)

One behavioral method allowing for multi-dimensional measures and for a mapping of the temporal dynamics of processing is the SAT procedure (e.g., McElree, 1993; McElree & Griffith, 1995). This method can dissociate the occurrence of a processing conflict from the final evaluation of a sentence by separating processing dynamics from time-independent aspects of the evaluation process. Combining SAT and ERP measures, Bornkessel, McElree, et al. (2004) examined the contrast between sentences such as in Examples 19b and 20, repeated here as Examples 30a and 30b, respectively.

. . . dass Gisbert Studentinnen folgen.
. . . that Gisbert$_{\text{AMB.SG}}$ students$_{\text{AMB.PL}}$ follow$_{\text{-DAT.PL}}$
". . . that students follow Gisbert." (30a)

. . . dass Dietmar Sopranistinnen auffallen.

[10] *Ergative-absolutive alignment* refers to a situation in which the subject of an intransitive sentence and the object of a transitive sentence are coded by the same morphological case, whereas the transitive subject is assigned a distinct case, the ergative. The case which marks the transitive object and intransitive subject is often referred to as *absolutive* (see Dixon, 1994, for a detailed description). In the vast majority of languages showing this coding pattern, it is the absolutive argument that agrees with the verb.

. . . that Dietmar$_{AMB.SG}$ sopranos$_{AMB.PL}$ is-striking-to$_{PL}$

"... that sopranos are striking to Dietmar." (30b)

In terms of their final acceptability, Examples 30a and 30b differ in that the former is less acceptable than the latter, despite the fact that both sentences are object-initial and locally case ambiguous (Schlesewsky & Bornkessel, 2003). Recall, however, that the clause-final object-experiencer verb *auffallen* ("to be striking to") in Example 30b supports the object-initial order, thereby leading to a higher acceptability. According to the eADM, both structures lead to increased processing costs in the COMPUTE LINKING step of Phase 2b because of the agreement mismatch engendered by the plural verb (with no LAN elicited in the ESTABLISH AGREEMENT step because the +agrt feature was assigned via MINIMALITY and not via a GR). Recall from above that the increased processing difficulty in the COMPUTE LINKING step engenders an N400 in both cases, because only a single GR is involved. The two structures differ, however, in that the ERP effect is less pronounced in Example 30b, thus paralleling the greater accessibility of the object-initial structure in this case. Strikingly, the SAT data reported by Bornkessel, McElree, et al. (2004) exactly mirror these two facets of processing: Although there was a general effect of word order on processing dynamics (i.e., object-initial structures were associated with longer SAT intercepts and thus processed more slowly than their subject-initial counterparts), the final acceptability (as reflected in SAT asymptote) was higher for the structure with an object-experiencer verb (see Example 30b). Thus, the dynamic aspects of the SAT data can be associated with the increased processing difficulty in Phase 2 and more precisely with the interaction between the ESTABLISH AGREEMENT and COMPUTE LINKING steps. By contrast, the asymptote difference, which corresponds to the amplitude of the N400, reflects the interaction between Phases 2b and 3.

Eyetracking

Eyetracking is a second behavioral method allowing for a dissociation of different subcomponents of processing (Rayner, 1998). Similarly to the SAT findings discussed above, one would therefore expect to find at least a partial correspondence between eyetracking measures and different processing steps within the eADM. A first indication that this may indeed be feasible stems from findings by Scheepers, Hemforth, and Konieczny (2000), who examined sentences such as

Vielleicht ängstigte die stille Schülerin der strenge Lehrer ein wenig,

perhaps frightened the$_{NOM/ACC}$ quiet pupil the$_{NOM}$ strict teacher a little

so wurde vermutet

so was suspected

"People suspected that the strict teacher perhaps frightened the quiet pupil a little." (31)

Similar to Example 30, Example 31 involves the disambiguation toward an object-initial reading, here via the case marking of the second argument. Here, too, the verb preceding the arguments renders an object-initial structure more acceptable. As the eADM would predict, Scheepers et al. observed a general disadvantage for the object-initial reading in terms of first-pass reading times at the disambiguating position. By contrast, the regression path durations for the sentence-final adverbial phrase revealed an interaction between word order and verb class, thereby indicating that, at the end of the sentence, object-initial orders were easier to process in the context of an accusative object-experiencer verb such as *ängstigen* ("to frighten") than after subject-experiencer verbs such as *fürchten* ("to fear"; i.e., verbs in which the subject experiences a psychological state and therefore bears the Experiencer role). As accusative object-experiencer verbs do not lead to a reversed linking relation between cases and thematic roles (see Footnote 6), we would not expect to observe an influence of verb type in Phase 2. Rather, the late modulation observed in the eyetracking results directly reflects properties of GENERALIZED MAPPING/WELL-FORMEDNESS in Phase 3 of the eADM.

A second example for a close correspondence between eyetracking and ERP results stems from visual world studies on grammatical function ambiguities in German (Knoeferle, Crocker, Scheepers, & Pickering, 2005; Knoeferle, Habets, Crocker, & Münte, 2005). In an initial visual world study, Knoeferle and colleagues found that a visual context was used by listeners to disambiguate a case-ambiguous clause-initial argument (e.g., *die Prinzessin*, "the princess" in Example 32) toward the dispreferred object reading even before the disambiguating case information of the second NP was encountered in the acoustic signal.

Die Prinzessin malt offensichtlich der Fechter.

[the princess]$_{AMB}$ paints obviously [the fencer]$_{NOM}$

"The fencer is obviously painting the princess." (32a)

Die Prinzessin wäscht offensichtlich den Piraten.

[the princess]$_{AMB}$ washes obviously [the pirate]$_{ACC}$

"The princess is obviously washing the pirate." (32b)

Participants in Knoeferle, Crocker, et al.'s study were shown a display with three characters: the case-ambiguous character (a princess) and two further characters that were either the agent of an action affecting the ambiguous character (a fencer, who is painting the princess) or the patient of an action carried out by the ambiguous character (a pirate, who is being washed by the princess). In sentences such as in Example 32a, participants preferentially looked at the agent argument of the OVS structure (the fencer) as opposed to the third figure in the visual scene (the pirate), which was compatible with the preferred SVO reading (as in Example 32b) but contradicted the verb information already given. Knoeferle and colleagues concluded that visual scene information can serve to disambiguate grammatical function ambiguities even before unambiguous linguistic information is available to support one or the other reading.

This observation is further supported by the results of a subsequent ERP study (Knoeferle, Habets, et al., 2005), in which the visually-induced disambiguation towards the object-initial reading elicited a P600 at the position of the verb, which provided only enough information for the scene to be able to disambiguate but, independently of the scene, remained compatible with both readings. Strikingly, the P600 effect observed by Knoeferle, Habets, et al. at the position of the verb closely mirrors the effect reported by beim Graben et al. (2000) for a disambiguation via number agreement at an identical sentence position. These results therefore not only point towards a possible role of visual information in the disambiguation of argument linking, but also suggest a high degree of convergence between the experimental methods.[11]

Both the eye-tracking and the SAT data discussed above therefore mirror the separation between Phase 2 and Phase 3 in terms of the eADM. In the first two examples discussed above, the data show a dissociation between (a) an initial processing conflict in Phase 2 and (b) a more general integration mechanism in Phase 3, reflecting not only the conflict itself, but also the factors influencing its resolution and/or the final evaluation of the sentence structure. This discussion thus provides a first indication that the findings from both methods can show a rather direct correspondence to the neurophysiological foundations of the model. Whether the relation between the different methods should always be expected to be as close as in these examples, however, remains an open question at present.

A final remark in this regard concerns one of the most conspicuous problems arising in the direct comparison between eye movements and ERP effects, namely mismatches in the timing information provided by the two methods (Sereno & Rayner, 2003). At the sentence level, this phenomenon can be illustrated with reference to gender agreement conflicts (Deutsch & Bentin, 2001), which showed a correlation between first pass reading times (in the order of approximately 250–320 ms) and the P600 (in a time window between 500 and 750 ms). A second finding of this type concerns the relationship between eyetracking and ERP correlates of lexical factors such as word frequency, repetition, semantic priming, and predictability. These properties reliably correlate with first fixation times (see Staub & Rayner, in press, for an overview) and are typically associated with N400 effects (Kutas & Federmeier, 2000). Again, the eye movements thus appear to temporally precede the electrophysiological effects.

For a satisfying solution of this issue, several questions must be addressed. For example, which parameters of an ERP effect should be viewed as correlating with the critical eye movement measures (as the onset of an N400 effect, e.g., is typically in the vicinity of 250 ms and thus much earlier than the component's maximum)? Assuming that linguistically-driven eye movements require the relevant information to have been processed by higher order brain regions (e.g., superior temporal or inferior frontal regions), how can the eyes' response to the processing accomplished by these regions be observable earlier than direct neural correlates (e.g., ERPs) of this processing?

Whereas the first question cannot be addressed satisfactorily at present, recent developments in EEG research allow us to at least sketch out a possible solution for the second issue. It has been argued that ERP components can be interpreted as modulations of underlying oscillatory activity in different frequency bands (Basar, 1998, 1999). From this perspective, the appearance of an ERP component results from a phase resetting of this underlying activity (Makeig et al., 2002), with the latency of the component depending upon the frequency band(s) within which the critical information is processed and, hence, within which the phase reset occurs (Dogil, Frese, Haider, Roehm, & Wokurek, 2004; Roehm et al., in press). Dogil et al. (2004) proposed that different linguistic information types are correlated with different frequency bands, thus resulting in the relative timing differences of information processing (i.e., essentially in successive phases of processing). With respect to eyetracking findings, this might mean the following: Phase resetting, as a general reflection of processing conflict, directly impacts upon the eyetracking record, whereas the latency of the corresponding ERP component depends upon the frequency range within which the critical information is processed. Because language-related ERP components reflect relatively slow frequency activity (between approximately 0.5 and 5 Hz; Roehm, 2004), it follows that the ERP response to such a phase resetting mechanism cannot be observably instantaneously. Note that we do not mean to suggest by this that all ERP effects necessarily result from a single phase reset. Rather, phase resetting may take place in all phases of comprehension, as indicated by the observed interdependence between the phases (i.e., an ELAN blocks an N400 but not vice versa).

In summary, we do not believe that the relative timing of ERP effects and eye movement responses shows principled incompatibilities. Nonetheless, it is clear that much more comparative research is required for researchers to fully understand how the two methods relate to one another.

The eADM in Comparison With Related Models of Language Comprehension

In this final section, we discuss the relation between the eADM and other models of language comprehension. In view of the two main characteristics of the model, namely its neurocognitive and cross-linguistic orientation, the discussion focuses primarily on a comparison of the eADM with other models sharing these goals. There are, of course, further models of sentence comprehension that address partially related issues to those under examination here. However, as discussed in the introductory section, none of these models was designed to derive processing correlates of simple transitive sentences across languages. We thus refrain from discussing these models in this section. However, the models that we do discuss, because of the greater degree of overlap, often share certain problems with these more general classes of models, which we point out in the relevant places. In the following, we therefore first examine alternative neurocognitive approaches, before turning to the most prominent behavioral approach to cross-linguistic sentence comprehension.

The Neurocognitive Model of Sentence Comprehension

Friederici's (1999, 2002) neurocognitive model of auditory sentence comprehension grew out of the aim to provide a neurocognitive implementation of the classical assumptions of two-stage processing models (Frazier & Fodor, 1978; Frazier & Rayner, 1982). On the basis of fine-grained neurophysiological data, these architectural assumptions were extended to a three phase processing model, with hierarchical dependencies holding between each

[11] The comparison between eyetracking and ERP data raises the more general question of whether the relatively slow presentation rates typically employed in visual ERP experiments may somehow influence the pattern of results observed in these studies. This appears unlikely for the first two phases assumed within the model, as most of the key results for these phases have been observed in both the visual and auditory modalities (see the text for references). However, we would not entirely rule out such an influence for Phase 3 of processing, particularly in view of the task-related nature of this phase.

of the phases. In Friederici's model, Phase 1 encompasses basic processes of constituent structuring that draw exclusively upon word category information, followed by morphosyntactic and lexical-semantic processing as well as thematic role assignment in Phase 2. It is important to note that formal and interpretive properties are processed in parallel but independent of one another in the second phase. Finally, Phase 3 is the locus of reanalysis and repair mechanisms, should these be required, and allows for an interaction of the information types processed independently of one another in Phase 2. The model is based on a number of neurophysiological and neuroanatomical findings (EEG/MEG/fMRI) within both the visual and the auditory modality (for a recent extension, see Friederici & Alter, 2004). The eADM thus follows Friederici's model in assuming (a) a subdivision of (post-phonological) processing into three phases, (b) a temporal and hierarchical ordering between these three phases, and (c) a predominance of word category information within the initial processing phase. Beyond these common assumptions, however, the two models differ in a number of important respects.

First, for Phase 1, the eADM assumes templates rather than phrase structure rules. Although both representations are essentially equivalent (the former being a precompiled variant of the latter; see the section *Representational Assumptions and Their Cross-Linguistic Motivation*), we have argued that there exist certain processing phenomena which may be accounted for more elegantly in a template-based account of phrase structure (see Bornkessel & Schlesewsky, 2006). Nonetheless, the basic conception of Phase 1 is very similar in the two models.

The main differences between the neurocognitive model and the eADM are to be found in Phases 2 and 3. In fact, the eADM provides an entirely new conceptualisation of these two phases and the relationship between them. Lexical-semantic processing in Friederici's (1999, 2002) sense does not form part of Phase 2 of the eADM at all, as it does not constitute an aspect of core constituent processing (Bornkessel, 2002; Schlesewsky & Bornkessel, 2004). Rather, Phase 2 of the eADM is centered around the establishment of agreement relations (the formal dimension), the assignment of prominence properties and GRs to arguments (the interpretive dimension), and the linking between verb and argument properties to produce a coherent semantic representation. As a consequence, the eADM's classification of particular information types to linguistic subdomains differs fundamentally from the Friederici model as well as from the original garden-path theory: Animacy, for example, forms an integral part of prominence computation (and, in certain languages, of linking) and is therefore not considered a lexical-semantic feature in the classical sense, but rather part of the interface between form and meaning. Also in accordance with linking requirements, Phase 2 introduces a subdivision into processing steps for predicating versus nonpredicating input items, and a separation into Phase 2a and Phase 2b (decoding vs. processing). Moreover, whereas Friederici's model assumes parallel, but independent processing pathways within Phase 2 of comprehension, the eADM introduces a hierarchical ordering between different processing steps within this phase (e.g., the assignment of ±agrt crucially depends on the outcome of the COMPUTE PROMINENCE step for nonpredicating elements).

Perhaps most important, the eADM explicitly aims to separate universal aspects of processing from processing steps (information types) specific to particular languages. Thus, information regarding the prominence of an argument is modeled independently of (a) structural position (templates in Phase 1 vs. linking in Phase 2) and (b) agreement (i.e., a "privileged formal status"). Consequently, the information types drawn upon by the processing mechanisms in Phase 2 differ from language to language. Furthermore, the eADM's assumption that the primary burden of sentential argument interpretation rests on the COMPUTE LINKING step in Phase 2b is a genuine innovation within the domain of sentence processing theories. This idea results in a number of important consequences. Not only does the linking-based perspective entail a direct interaction of generalized roles, agreement, voice, and LS in the association between arguments and verbs, it also implies that certain processes which are attributed to Phase 3 in the Friederici (1999, 2002) model (namely, grammatical function reanalysis) should be modeled as a part of Phase 2. Thus, the eADM leads to a fundamental shift with respect to the division of power between Phases 2 and 3, with all aspects of the form-to-meaning mapping relating to core relations being situated in Phase 2, and all modulating, reparatory, and evaluative aspects of processing taking place in Phase 3. Phase 3 of the eADM therefore allows for modeling of task-related influences in the WELL-FORMEDNESS step, thereby integrating sentence comprehension with more general aspects of higher cognition. Finally, Phase 3 incorporates an explicit GENERALIZED MAPPING step that is independent of possible repair operations and the WELL-FORMEDNESS check. This processing step, which is not modeled explicitly in Friederici's approach, allows for the systematic investigation of how core information is integrated with noncore information both within a language and cross-linguistically (for further discussion, see section *The Competition Model* below).

In summary, although the eADM acknowledges its basic architectural heritage in the neurocognitive model's assumption of three processing phases and the predominance of word category information in the initial phase of processing, the restructuring and reformulation of Phases 2 and 3 as well as the typological orientation of the eADM attest to the fact that this model should not be viewed simply as an extension of the neurocognitive model.

The Declarative/Procedural Model

An entirely different conceptualisation of the neural basis for language comprehension—and particularly of the interplay between syntax and semantics—has been proposed within the declarative/procedural model (Ullman, 2001, 2004). In accordance with the more general differentiation between declarative and procedural memory, Ullman (2001, 2004) proposed that (rule-based) syntactic knowledge should be viewed as part of the procedural system, whereas (lexically stored) semantic information is represented as a declarative information type. As such, processing within the two linguistic subdomains is expected to engage the neural networks associated with the procedural and declarative memory systems, respectively. Moreover, Ullman proposed that the two systems are associated with distinct electrophysiological processing correlates, namely left-anterior negativities for syntax/procedural memory and N400 effects for lexical information/semantics/declarative memory. Late positivities, by contrast, are considered controlled processes rather than automatic aspects of procedural memory. In this way, Ullman's perspective on late positive effects appears potentially compatible with the eADM's association between this type of component and (at least partially task-related) Phase 3 processes such as the WELL-FORMEDNESS check.

A comparison between the declarative/procedural model and the eADM reveals, first, a discrepancy with respect to the grain of the information types assumed to play a role within the two approaches. Whereas the declarative/procedural model is essentially based on a dissociation between lexical/semantic (declarative) and syntactic (procedural) information, the eADM posits a number of more fine-grained differentiations which are not easily derivable from such a binary distinction. For example, it is very difficult to see how the relational information types which serve as an interface between form and meaning within the eADM (GRs, prominence hierarchies) could neatly fit into either one or the other category. More important, the direct association between particular ERP components and the different memory systems cannot be upheld in the face of recent findings (e.g., the N400 effect for grammatical function reanalysis, see the section on the interaction between ESTABLISH AGREEMENT and COMPUTE LINKING above). The declarative/procedural model thus leads to a number of empirically inadequate predictions, which, from our perspective, are a consequence of an oversimplified conceptualisation of language.

A similar line of argumentation applies to the neuroanatomical assumptions of the declarative/procedural model. Here, Ullman (2001, 2004) assumes that the procedural system comprises a network of frontal (including the pars opercularis and triangularis of the IFG and premotor regions), parietal, cerebellar, and basal-ganglia structures, whereas the declarative system is thought to draw primarily upon regions in the medial temporal lobe. Superior temporal regions are viewed as a possible locus for mediation between the two systems. From this perspective, inferior frontal and basal ganglia activations engendered by increased syntactic processing demands are viewed as resulting from the involvement of the procedural system. Again, this perspective appears somewhat oversimplified. As discussed in the section on the neuroanatomical correlates of Phase 2 processing, the application of prominence hierarchies during online comprehension directly modulates the activation of the pars opercularis of the IFG. Thus, it appears very difficult to account for language-related activation of left inferior frontal regions solely in terms of procedural memory.

In summary, although we believe that the declarative/procedural model constitutes an interesting attempt to account for language comprehension mechanisms and their neural bases in terms of more general cognitive (memory) systems, the simple dichotomy between declarative and procedural information assumed in this model does not appear to capture the inherent complexity of language and the neurophysiological/neuroanatomical correlates of this complexity.

The Memory, Unification, and Control (MUC) Framework

A third proposal regarding the neural basis of syntactic processing was recently put forward by Hagoort (2003, 2005). Adopting the psycholinguistic assumptions of Vosse and Kempen's (2000) template-based unification model, Hagoort proposed that the storage and retrieval of templates (syntactic frames) is supported by the posterior portion of left superior temporal cortex, and template unification (binding) is accomplished by left inferior frontal areas. Notably, the templates assumed within this approach differ markedly from those forming part of the eADM, as they are attached to individual lexical items and encode a variety of different information types (e.g., categories such as noun; functions such as subject). Although the claim that the storage of lexical representations correlates with posterior superior temporal brain regions appears plausible in view of the existing neuroscientific data, the association between Broca's region and unification operations raises a number of problems which we will discuss in turn in the following. In particular, we focus on the claim that BA 44 and, to a lesser degree BA 45, support the unification of syntactic structures.

First, recall from the section on neuroanatomical correlates of Phase 2 of the eADM that BA 44 shows higher activation in sentences with an object-before-subject order. To derive this finding via unification of fully specified templates, one would either have to assume templatic differences between the object- and subject-initial structures (thus yielding differences in unification operations) or appeal to some other mechanism such as increased competition between the subject- and object-initial orders. The latter possibility was assumed by Vosse and Kempen (2000, p. 134 ff.) in their original model, thus allowing them to derive the difference between subject (SVO) and object (SOV) relative clauses in English because of the fact that the two preverbal NPs in object relatives lead to increased competition for the subject role. However, neither of the two options is viable for verb-final languages such as German, Japanese, Turkish, and Hindi, as here (a) general structural differences between SOV and OSV order would presuppose lexically independent templates and template combination operations, which are excluded in Hagoort's framework (Hagoort, 2005, p. 417), and (b) the two preverbal NPs would always be in competition with one another in these languages, thus rendering a simple competition-based account of the increased BA 44 activation for scrambling in German unlikely.

Vosse and Kempen (2000, pp. 138–139) acknowledged that the issue of preverbal argument interpretation in verb-final languages is potentially problematic for their strictly head-driven (i.e., fully lexically based) unification model, the architecture of which Hagoort (2005) fully adopts. They do, however, propose two possible ways of circumventing this problem, namely (a) in terms of the frequency of occurrence of nonnominative case "occupying the first few positions after a subordinating conjunction or a sentence boundary" (Vosse & Kempen, 2000, p. 138) or (b) with reference to a frequency-based, presyntactic case-assignment mechanism. The second option is at odds with the numerous findings showing not only that morphological case leads to processing difficulties when it is encountered in a noncanonical position, but that it is actively used by the processing system to assign an interpretation to an NP (e.g., in terms of GRs) before the verb is reached (see the section on electrophysiological correlates above). The first possibility, translated into Hagoort's framework, would imply that activation differences for preverbal argument order variations within BA 44 should correlate with differences in the frequency of occurrence of the critical structures. However, this is not borne out in existing findings addressing this issue: Grewe et al. (2005) showed that the activation pattern within BA 44 is orthogonal to frequency differences (for more general problems with frequency-based approaches to word order variations, see Bornkessel et al., 2002b; Crocker & Keller, 2006; Kempen & Harbusch, 2005).

Furthermore, word order effects in BA 44 extend beyond grammatical functions. In German, a violation of the semantically-based word order rule animate-before-inanimate leads to increased activation in BA 44 (Grewe et al., in press). This finding cannot be derived via unification, as (a) the assumption of different unification operations in the two structures contradicts Hagoort's basic premises (see above) and (b) the integration of word-order relevant features such as animacy, thematic roles (Bornkessel et al., 2005) and referential status (Grewe et al., 2005) into the templates yields an exponential increase of the number of templates that must be available in parallel. For transitive verbs in German alone, this results in a total of 192 templates for each individual verb.[12]

Third, a large number of studies examining syntactic complexity during language comprehension—which, in Hagoort's (2005) approach, should be a prime candidate for unification cost—not only reported inferior frontal activation, but also observed neural correlates of increased unification cost within the cortical regions assumed to support Hagoort's memory component, namely in left superior temporal cortex (e.g., Ben-Shachar et al., 2003, 2004; Bornkessel et al., 2005; Constable et al., 2004; Just et al., 1996; Röder et al., 2002). The consequences of such findings for Hagoort's approach are not at all clear.

Finally, and perhaps most gravely, the MUC's architecture is subject to severe problems when considered from a cross-linguistic perspective. The templates assumed by Vosse and Kempen (2000) and adopted by Hagoort (2005) include both word category and relational information (i.e., grammatical functions and, by extension, thematic interpretations). As argued extensively throughout the present article, such a direct association between phrase structure and relational argument interpretation is very difficult to motivate for languages other than those of the English type. Thus, in its current form, the MUC model is only applicable in languages with a position-based interpretation strategy. For all other languages, an additional linking system or language-specific template inventories encoding all possible relations between linear order and argument interpretation would need to be implemented.

In summary, the MUC raises a number of major empirical issues that have not as yet been discussed in the publications introducing this framework. Although we therefore cannot exclude that future extensions of the model will be able to account for the types of phenomena discussed above, we believe that the conceptual basis of the model leads to a number of shortcomings with respect to the relational aspects of sentence comprehension and, in particular, to their cross-linguistic implementation.

The Competition Model

With respect to the question of cross-linguistic similarities and differences in sentence comprehension, the model that is currently best established in the literature is the competition model (Bates, McNew, MacWhinney, Devescovi, & Smith, 1982; MacWhinney & Bates, 1989). This model assumes that sentence comprehension consists of a direct form-to-function mapping based on a variety of interacting cues (e.g., word order, animacy, agreement, stress). Cue strength varies from language to language and is based on the notion of cue validity, which results from a combination of cue applicability (which is high when a cue is always available) and cue reliability (which is high when a cue is always unambiguous and never misleading). The interpretation of a sentence (e.g., with respect to the question of which argument is identified as the actor of the event being described) is thought to result from a competition between different cues. This means that all cues are activated in parallel and interact with one another to produce the winning interpretation on the basis of relative cue strength. In comparison to other lexicalist constraint-based models (e.g., MacDonald et al., 1994), the competition model appears better suited to modeling cross-linguistic findings (particularly in verb-final languages), as it (at least implicitly) assumes an abstract, rather than a verb-based, representation of the some of the relevant cues (see, e.g., the connectionist simulation in Kempe & MacWhinney, 1999; cf. also recent approaches to syntax and syntactic processing in nonlexicalist, competition-based approaches, Fanselow et al., 1999; Jackendoff, 2002; Stevenson & Smolensky, 2006).

The claims of the competition model are highly relevant to the approach adopted within the eADM, because they seek to model how sentence interpretation in different languages is governed by different information types (depending on cue validity). On the basis of behavioral comprehension studies in English, German, and Italian, for example, MacWhinney et al. (1984) argued for the following cue rankings: word order > agreement, animacy (English); agreement > animacy > word order (Italian); animacy > agreement > word order (German). The competition model thus provides a framework for modeling the outcome of the (whole sentence) interpretation process across different languages.

How, then, do the assumptions of the competition model relate to those of the eADM? The most important point to note in this regard concerns the nature of the data with which the two approaches are concerned: while the competition model draws primarily upon offline decisions with respect to entire sentences, the eADM attempts to derive the processing choices at each local step during the online comprehension process. Note that several findings attest to the fact that these two dimensions need not necessarily show a perfect correspondence. For example, Schlesewsky, Fanselow, Kliegl, and Krems (2000) showed that the subject-first preference in German is unaffected by whether the initial (ambiguous) argument is animate or inanimate, despite the fact that MacWhinney et al., (1984) identified animacy as the strongest cue for actor identification in German. Conversely, Weckerly and Kutas' (1999) finding of a local animacy effect for subject arguments in English shows that a cue with low validity in a particular language may influence online processing even though it barely contributes to final sentence interpretation. Finally, as motivated throughout the present article, there is good evidence that, during

[12] We arrive at the number of 192 (for subordinate clauses with two arguments) in the following way. Subjects can precede objects or vice versa (2), the first NP can outrank the second in terms of thematic roles or vice versa (2), both NPs can be animate or inanimate (4), both NPs can be definite or indefinite (4), and both NPs can be either pronominal or non-pronominal. For sentences with full NPs, we therefore arrive at $2 \times 2 \times 4 \times 4 = 64$ possibilities, and for sentences with pronouns (which cannot be indefinite), we end up with $2 \times 2 \times 4 \times 2 = 32$ possible orderings. As subordinate clauses in German are either of the form NP V NP or (that) NP NP V, the grand total of linear orderings that must be modeled is thus $(64 + 32) \times 2 = 192$. For evidence that each of these parameters plays a role in the processing of German, see Bornkessel et al., 2005; Bornkessel, Schlesewsky, and von Cramon, 2006; Grewe et al., 2005; Grewe et al., in press.

online comprehension, the formal level of argument analysis ("subjecthood" in traditional terms; +agrt in the eADM framework) and the interpretive level (actorhood) do not always correspond. However, these levels are not differentiated within the competition model.

In view of these considerations, we believe that the cue rankings provided by the competition model may be considered an output of the online comprehension system. As such, they correspond to Phase 3 processes within the eADM. Although the most plausible candidate processing step in this respect appears to be GENERALIZED MAPPING, because this step serves to integrate a wide variety of core-internal and core-external information types that did not interact in prior processing Phases, we would also presently not exclude a contribution of the WELL-FORMEDNESS check. This association would serve to model possible task-based influences on final sentence interpretation, should these occur.

In summary, the competition model and eADM complement one another in interesting and potentially fruitful ways. In particular, the many findings on offline argument interpretation that have been gathered in support of the competition model provide us with a valuable point of departure for future investigations on (a) the internal structure of Phase 3 of the eADM and (b) the interaction between neurocognitive phenomena during online processing and sentence-final interpretation.

Outlook: The Relationship Between the eADM and Psychological Theories

Clearly, the eADM is a model that is based on linguistic premises. This raises the question of how the mechanisms assumed here might relate to—or possibly even derive from—concepts from cognitive psychology. However, such an association is presently not easily drawn because of the level of complexity inherent to the data pattern under examination. Thus, even in simple sentences containing only obligatory arguments, we are confronted with an interaction of multiple, hierarchically structured relational information types. Furthermore, the crucial role of (at least certain aspects of) linguistic structure in deriving the qualitative distinctions described in the present article are not easily explained in general cognitive terms: Recall, for example, the difference between clause-initial and clause-medial object-initial orders in German or the differences in grammatical function reanalyses between sentences with accusative and dative objects.

However, beyond the issues of structure dependence and relational complexity per se, perhaps the primary challenge that we see for psychological theory lies in the modeling of what the eADM conceptualises as prominence hierarchies. Recall that the cross-linguistic findings discussed in this article provide strong converging evidence for the interaction of multiple relational hierarchies that apply independent of any verb-specific information. This crucial property of the comprehension architecture, which might be referred to as "predicate independence," is required to account for the rich interpretive processes that take place in verb-final languages even before the verb is encountered. By contrast, even very sophisticated cognitive models of relational processing and reasoning typically rely on predicate-based role activation for the initiation of filler-to-role bindings (i.e., the analogue of argument interpretation; Halford, Wilson, & Phillips, 1998; Hummel & Holyoak, 1997).

Furthermore, predicate independence is not the only issue raised by preverbal argument interpretation. If this were the case, a possible solution might simply lie in the introduction of predicate-independent representations (akin to "generalized role nodes") that could, for example, be activated on the basis of morphological case. However, as discussed in detail in this article, this type of one-dimensional mapping perspective does not suffice. Rather, our data suggest that preverbal argument interpretation draws upon a variety of interacting, hierarchically structured information types (including, e.g., animacy, definiteness/specificity) Moreover, the mapping between an argument and its corresponding prominence status not only depends on the properties of that argument itself, but may further draw upon the relation of that argument to its coargument(s). As an illustration, consider the effects of animacy discussed in various sections of this article: An inanimate subject preceding an animate (dative) object is dispreferred in German, but an inanimate subject without a second argument or preceding an inanimate object is not problematic. In languages such as Fore, this type of relation is of vital importance for computing the correct interpretation of a sentence.

It appears plausible that the computation of an argument's prominence status from these interacting and potentially conflicting hierarchies may be related to more general mechanisms involved in the selection of a critical representation from a set of competing alternatives (cf. Thompson-Schill et al., 2005). Such an association receives converging support from the empirical observation that selection mechanisms of this type crucially draw upon the same neural substrate implicated in the processing of prominence hierarchies, namely the pars opercularis of the left IFG (BA 44; Thompson-Schill et al., 1997). However, from a domain general perspective, it is presently not at all clear how the information that this selection operates upon should be represented and how the interaction between all available information types can be constrained.

Finally, from a cross-linguistic perspective, the hierarchical encoding of prominence relations is rendered more complex by the availability of more than two morphosyntactic coding categories (e.g., the availability of dative case in addition to nominative and accusative). Yet it is questionable whether the existence of a third case also justifies the assumption of a third generalized role that would enable a straightforward form-to-meaning mapping (see Van Valin, 2005, for arguments against a third GR). For example, a third role would not sufficiently capture the fact that a dative sometimes encodes an opposition to a nominative (e.g., in coding an experiencer rather than an agent role) and, in other constructions, encodes an opposition to an accusative (i.e., in signalling that the object is not maximally affected by the event being described).

In summary, the cross-linguistic requirements of processing even the most basic utterances—and particularly the consequences of incremental interpretation in verb-final languages—pose a particular challenge for language-oriented cognitive modeling. Nonetheless, we do not mean to suggest that the mechanisms forming part of the eADM are in principle incompatible with more general cognitive concepts. Rather, with the eADM, we have chosen to approach the challenge of how the complexity of language and more general cognitive concepts fit together from the other side, namely, by providing a detailed linguistically-based model of what might be considered the essential component parts of the comprehension architecture. In this way, we have identified a number of issues that arise specifically from the combination of a cross-linguistic perspective and neurocognitive measurement techniques, thus providing an entirely new basis for the question of which cognitive ingredients are required to adequately model language comprehension. As pointed out above and in various places throughout this article, a number of promising associations can already be drawn. However, it appears clear that a great deal of further integrative research will be required to see how general cognitive concepts might serve to adequately capture the fascinating diversity of the languages of the world and the neurocognitive mechanisms allowing for them to be processed in real time.

Conclusion

We have presented a neurocognitive model of language comprehension—the eADM—that provides a new approach to cross-linguistic differences and similarities in the processing of core relations. The primary motivation for the eADM lies in the observation that the processing of clearly distinct structures in different languages may lead to identical neurophysiological effects, whereas, conversely, apparently identical structures can engender dissimilar processing patterns. Such seemingly puzzling divergences are accounted for within the model by way of the assumption of rather general underlying mechanisms that are shared across languages (e.g., the establishment of argument hierarchies and the assignment of GRs) in combination with a language-particular specification of these mechanisms (e.g., in terms of the properties that are informative with regard to GR assignment). The eADM thus provides the first comprehensive framework for understanding the real time comprehension of simple, transitive sentences—the primary building blocks of language-based communication—and the cross-linguistic unity and diversity of this fundamental human ability.

References

Allen, C. L. (1995). *Case marking and reanalysis: Grammatical relations from old to early modern English.* Oxford, England: Oxford University Press.

Bader, M., & Meng, M. (1999). Subject-object ambiguities in German embedded clauses: An across-the-board comparison. *Journal of Psycholinguistic Research, 28,* 121–143.

Basar, E. (1998). *Brain function and oscillations: Principles and approaches.* Berlin, Germany: Springer.

Basar, E. (1999). *Brain function and oscillations II: Integrative brain function. Neurophysiology and cognitive processes.* Berlin: Springer.

Bates, E. (1976). *Language and context: Studies in the acquisition of pragmatics.* New York: Academic Press.

Bates, E., McNew, S., MacWhinney, B., Devescovi, A., & Smith, S. (1982). Functional constraints on sentence processing: A cross-linguistic study. *Cognition, 11,* 245–299.

beim Graben, P., Schlesewsky, M., Saddy, J. D., & Kurths, J. (2000). Symbolic dynamics of event-related brain potentials. *Physical Review E, 62,* 5518–5541.

Ben-Shachar, M., Hendler, T., Kahn, I., Ben-Bashat, D., & Grodzinsky, Y. (2003). The neural reality of syntactic transformations: Evidence from functional magnetic resonance imaging. *Psychological Science, 14,* 433–440.

Ben-Shachar, M., Palti, D., & Grodzinsky, Y. (2004). Neural correlates of syntactic movement: Converging evidence from two fMRI experiments. *Neuroimage, 21,* 1320–1336.

Bickel, B. (2003). Referential density in discourse and syntactic typology. *Language, 79,* 708–736.

Bierwisch, M. (1988). On the grammar of local prepositions. In M. Bierwisch, W. Motsch & I. Zimmermann (Eds.), *Syntax, semantik und lexikon* (pp. 1–65). Berlin, Germany: Akademie Verlag.

Bisang, W. (2006). From meaning to syntax: Semantic roles and beyond. In I. Bornkessel, M. Schlesewsky, B. Comrie, & A. D. Friederici (Eds.), *Semantic role universals and argument linking: Theoretical, typological and psycholinguistic perspectives* (pp. 191–236). Berlin, Germany: Mouton de Gruyter.

Bornkessel, I. (2002). *The argument dependency model: A neurocognitive approach to incremental interpretation* (Vol. 28). Leipzig, Germany: MPI Series in Cognitive Neuroscience.

Bornkessel, I., Fiebach, C. J., & Friederici, A. D. (2004). On the cost of syntactic ambiguity in human language comprehension: An individual differences approach. *Cognitive Brain Research, 21,* 11–21.

Bornkessel, I., McElree, B., Schlesewsky, M., & Friederici, A. D. (2004). Multi-dimensional contributions to garden path strength: Dissociating phrase structure from case marking. *Journal of Memory and Language, 51,* 495–522.

Bornkessel, I., & Schlesewsky, M. (2006). Generalised semantic roles and syntactic templates: A new framework for language comprehension. In I. Bornkessel, M. Schlesewsky, B. Comrie, & A. D. Friederici (Eds.), *Semantic role universals and argument linking: Theoretical, typological and psycholinguistic perspectives* (pp. 327–353). Berlin, Germany: Mouton de Gruyter.

Bornkessel, I., Schlesewsky, M., & Friederici, A. D. (2002a). Beyond syntax: Language-related positivities reflect the revision of hierarchies. *Neuroreport, 13,* 361–364.

Bornkessel, I., Schlesewsky, M., & Friederici, A. D. (2002b). Grammar overrides frequency: Evidence from the online processing of flexible word order. *Cognition, 85,* B21–B30.

Bornkessel, I., Schlesewsky, M., & Friederici, A. D. (2003). Eliciting thematic reanalysis effects: The role of syntax-independent information during parsing. *Language and Cognitive Processes, 18,* 268–298.

Bornkessel, I., Schlesewsky, M., & von Cramon, D. Y. (2006). *The neural bases for linear order in language.* Manuscript submitted for publication.

Bornkessel, I., Zysset, S., Friederici, A. D., von Cramon, D. Y., & Schlesewsky, M. (2005). Who did what to whom? The neural basis of argument hierarchies during language comprehension. *NeuroImage, 26,* 221–233.

Bresnan, J., & Kanerva, J. M. (1989). Locative inversion in Chichewa: A case study of factorization in grammar. *Linguistic Inquiry, 20,* 1–50.

Calvert, G. A. (2001). Crossmodal processing in the human brain: Insights from functional neuroimaging studies. *Cerebral Cortex, 11,* 1110–1123.

Caplan, D., Alpert, N., Waters, G., & Olivieri, A. (2000). Activation of Broca's area by syntactic processing under conditions of concurrent articulation. *Human Brain Mapping, 9,* 65–71.

Caplan, D., Vijayan, S., Kuperberg, G. R., West, C., Waters, G., Greve, D., et al. (2001). Vascular responses to syntactic processing: Event-related fMRI study of relative clauses. *Human Brain Mapping, 15,* 26–38.

Carlson, G., & Tanenhaus, M. K. (1988). Thematic roles and language comprehension. In W. Wilkins (Ed.), *Syntax and semantics: Vol. 21. Thematic relations* (pp. 263–288). New York: Academic Press.

Carreiras, M., & Clifton, C., Jr. (Eds.). (2004). *The on-line study of sentence comprehension: Eyetracking, ERPs and beyond.* New York: Psychology Press.

Chomsky, N. (1981). *Lectures on government and binding.* Dordrecht, the Netherlands: Kluwer.

Comrie, B. (1989). *Linguistic universals and language typology* (2nd ed.). Oxford, England: Blackwell.

Constable, R. T., Pugh, K. R., Berroya, E., Mencl, W. E., Westerveld, M., Ni, W., et al. (2004). Sentence complexity and input modality effecs in sentence comprehension: An fMRI study. *Neuroimage, 22,* 11–21.

Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes, 13,* 21–58.

Crocker, M. W. (1994). On the nature of the principle-based sentence processor. In C. Clifton, Jr., L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 245–266). Hillsdale, NJ: Erlbaum.

Crocker, M. W. (1995). *Computational psycholinguistics: An interdisciplinary approach to the study of language.* Dordrecht, the Netherlands: Kluwer.

Crocker, M. W., & Keller, F. (2006). Probabilistic grammars as models of gradience in language processing. In G. Fanselow, C. Féry, R. Vogel, & M. Schlesewsky (Eds.), *Gradience in grammar: Generative perspectives* (pp. 227–245). Oxford, England: Oxford University Press.

Croft, W. (2003). *Typology and universals* (2nd ed.). Cambridge, England: Cambridge University Press.

Deutsch, A., & Bentin, S. (2001). Syntactic and semantic factors in processing gender agreement in Hebrew: Evidence from ERPs and eye movements. *Journal of Memory and Language, 45,* 200–224.

de Vincenzi, M. (1991). *Syntactic parsing strategies in Italian.* Dordrecht, the Netherlands: Kluwer.

de Vincenzi, M., Job, R., Di Matteo, R., Angrilli, A., Penolazzi, B., Ciccarelli, L., et al. (2003). Differences in the perception and time course of syntactic and semantic violations. *Brain and Language, 85,* 280–296.

Dixon, R. M. W. (1994). *Ergativity* (2nd ed.). Cambridge, England: Cambridge University Press.

Dogil, G., Frese, I., Haider, H., Roehm, D., & Wokurek, W. (2004). Where and how does grammatically geared processing take place—and why is Broca's area often involved: A coordinated fMRI/ERBP study of language processing. *Brain and Language, 89,* 337–345.

Dowty, D. (1991). Thematic proto-roles and argument selection. *Language, 67,* 547–619.

Dronkers, N. F., Wilkins, D. P., Van Valin, R. D., Jr., Redfern, B. B., & Jaeger, J. J. (2004). Lesion analysis of the brain areas involved in language comprehension. *Cognition, 92,* 145–177.

Fanselow, G. (2000). Optimal exceptions. In B. Stiebels & D. Wunderlich (Eds.), *Lexicon in focus* (pp. 173–209). Berlin, Germany: Akademie Verlag.

Fanselow, G. (2001). Features, θ-roles, and free constituent order. *Linguistic Inquiry, 32,* 405–437.

Fanselow, G., Schlesewsky, M., Cavar, D., & Kliegl, R. (1999). Optimal parsing: Syntactic Parsing preferences and optimality theory. *Rutgers Optimality Archive, 367.*

Fiebach, C. J., Schlesewsky, M., Bornkessel, I., & Friederici, A. D. (2004). Distinct neural correlates of legal and illegal word order variations in German: How can fMRI inform cognitive models of sentence processing. In M. Carreiras & C. Clifton, Jr. (Eds.), *The on-line study of sentence comprehension* (pp. 357–370). New York: Psychology Press.

Fiebach, C. J., Schlesewsky, M., & Friederici, A. D. (2002). Separating syntactic memory costs and syntactic integration costs during parsing: The processing of German wh-questions. *Journal of Memory and Language, 47,* 250–272.

Fiebach, C. J., Schlesewsky, M., Lohmann, G., von Cramon, D. Y., & Friederici, A. D. (2005). Revisiting the role of Broca's area in sentence processing: Syntactic integration versus syntactic working memory. *Human Brain Mapping, 24,* 79–91.

Fiebach, C. J., Vos, S. H., & Friederici, A. D. (2004). Neural correlates of syntactic ambiguity in sentence comprehension for low and high span readers. *Journal of Cognitive Neuroscience, 16,* 1562–1575.

Fodor, J. D. (1998). Learning to parse. *Journal of Psycholinguistic Research, 27,* 285–319.

Foley, W. A., & Van Valin, R. D., Jr. (1984). *Functional syntax and universal grammar.* Cambridge, England: Cambridge University Press.

Frazier, L. (1978). *On comprehending sentences: Syntactic parsing strategies.* Unpublished doctoral dissertation, University of Connecticut, Storrs.

Frazier, L. (1989). Against lexical generation of syntax. In W. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 505–528). Cambridge, MA: MIT Press.

Frazier, L., & Clifton, C., Jr. (1996). *Construal.* Cambridge, MA: MIT Press.

Frazier, L., & Flores d'Arcais, G. B. (1989). Filler-driven parsing: A study of gap filling in Dutch. *Journal of Memory and Language, 28,* 331–344.

Frazier, L., & Fodor, J. D. (1978). The sausage machine: A new two-stage parsing model. *Cognition, 6,* 291–326.

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology, 14,* 178–210.

Friederici, A. D. (1999). The neurobiology of language comprehension. In A. D. Friederici (Ed.), *Language comprehension: A biological perspective* (pp. 263–301). New York: Springer.

Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences, 6,* 78–84.

Friederici, A. D. (2004). Processing local transitions versus long-distance syntactic hierarchies. *Trends in Cognitive Sciences, 8,* 245–247.

Friederici, A. D., & Alter, K. (2004). Lateralization of auditory language functions: A dynamic dual pathway model. *Brain and Language, 89,* 267–276.

Friederici, A. D., Fiebach, C. J., Schlesewsky, M., Bornkessel, I., & von Cramon, D. Y. (in press). Processing linguistic complexity and grammaticality in the left frontal cortex. *Cerebral Cortex.*

Friederici, A. D., Hahne, A., & Saddy, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research, 31,* 45–63.

Friederici, A. D., & Kotz, S. A. (2003). The brain basis of syntactic processes: Functional imaging and lesion studies. *Neuroimage, 20,* S8–S17.

Friederici, A. D., & Mecklinger, A. (1996). Syntactic parsing as revealed by brain responses: First pass and second pass parsing processes. *Journal of Psycholinguistic Research, 25,* 157–176.

Friederici, A. D., & Meyer, M. (2004). The brain knows the difference: Two types of grammatical violations. *Brain Research, 1000,* 72–77.

Friederici, A. D., Rüschemeyer, S.-A., Fiebach, C. J., & Hahne, A. (2003). The role of left inferior frontal and superior temporal cortex in sentence comprehension: Localizing syntactic and semantic processes. *Cerebral Cortex, 13,* 1047–3211.

Friederici, A. D., Steinhauer, K., Mecklinger, A., & Meyer, M. (1998). Working memory constraints on syntactic ambiguity resolution as revealed by electrical brain responses. *Biological Psychology, 47,* 193–221.

Frisch, S., Hahne, A., & Friederici, A. D. (2004). Word category and verb-argument structure information in the dynamics of parsing. *Cognition, 91,* 191–219.

Frisch, S., Kotz, S. A., von Cramon, D. Y., & Friederici, A. D. (2003). Why the P600 is not just a P300: The role of the basal ganglia. *Clinical Neurophysiology, 114,* 336–340.

Frisch, S., & Schlesewsky, M. (2001). The N400 indicates problems of thematic hierarchizing. *Neuroreport, 12,* 3391–3394.

Frisch, S., & Schlesewsky, M. (2005). The resolution of case conflicts from a neurophysiological perspective. *Cognitive Brain Research, 25,* 484–498.

Frisch, S., Schlesewsky, M., Saddy, D., & Alpermann, A. (2002). The P600 as an indicator of syntactic ambiguity. *Cognition, 85,* B83–B92.

Frisch, S., Schlesewsky, M., & Wegener, H. (2005). The interaction of morphological case and word order constraints: Cross-linguistic ERP evidence from German, Russian and Finnish. *Journal of Cognitive Neuroscience, 17*(Suppl.), 26.

Frith, C. D., & Frith, U. (1999, November 26). Interacting minds—A biological basis. *Science, 286,* 1692–1695.

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society London, Series B, 358,* 459–473.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition, 68,* 1–76.

Gibson, E. (2000). The dependency locality theory: A distance-based theory of linguistic complexity. In Y. Miyashita, A. Marantz, & W. O'Neil (Eds.), *Image, language, brain* (pp. 95–126). Cambridge, MA: MIT Press.

Gibson, E., Hickok, G., & Schütze, C. (1994). Processing empty categories: A parallel approach. *Journal of Psycholinguistic Research, 23,* 381–405.

Gorrell, P. (1995). *Syntax and parsing.* Cambridge, England: Cambridge University Press.

Grewe, T., Bornkessel, I., Zysset, S., Wiese, R., von Cramon, D. Y., & Schlesewsky, M. (2005). The emergence of the unmarked: A new perspective on the language-specific function of Broca's area. *Human Brain Mapping, 26,* 178–190.

Grewe, T., Bornkessel, I., Zysset, S., Wiese, R., von Cramon, D. Y., & Schlesewsky, M. (in press). Linguistic prominence and Broca's area: The influence of animacy as a linearization principle. *Neuroimage.*

Grimshaw, J. (1990). *Argument structure.* Cambridge, MA: MIT Press.

Grober, E. H., Beardsley, W., & Caramazza, A. (1978). Parallel function strategy in pronoun assignment. *Cognition, 6,* 117–133.

Gunter, T. C., Stowe, L. A., & Mulder, G. (1997). When syntax meets semantics. *Psychophysiology, 34,* 660–676.

Hagoort, P. (2003). How the brain solves the binding problem for language: A neurocomputational model of syntactic processing. *Neuroimage, 20*(Suppl. 1), S18–S29.

Hagoort, P. (2005). On Broca, brain, and binding: A new framework. *Trends in Cognitive Sciences, 9,* 416–423.

Hagoort, P., & Brown, C. (2000). ERP effects of listening to speech compared to reading: The P600/SPS to syntactic violations in spoken sentence and rapid serial visual presentation. *Neuropsychologia, 38,* 1531–1549.

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes, 8,* 439–483.

Hahne, A. (1998). *Charakteristika syntaktischer und semantischer Prozesse bei der auditiven Sprachverarbeitung* (Vol. 1). Leipzig, Germany: MPI Series in Cognitive Neuroscience.

Hahne, A., & Friederici, A. D. (1999). Electrophysiological evidence for two steps in syntactic analysis: Early automatic and late controlled processes. *Journal of Cognitive Neuroscience, 11,* 194–205.

Hahne, A., & Friederici, A. D. (2002). Differential task effects on semantic and syntactic processes as revealed by ERPs. *Cognitive Brain Research, 13,* 339–356.

Haider, H. (1993). *Deutsche syntax, generativ.* Tübingen, Germany: Narr.

Haider, H., & Rosengren, I. (2003). Scrambling: Nontriggered chain formation in OV languages. *Journal of Germanic Linguistics, 15,* 203–267.

Halford, G. S., Wilson, W. H., & Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behavioral and Brain Sciences, 21,* 803–865.

Helbig, G., & Buscha, L. (1996). *Deutsche grammatik.* Leipzig, Germany: Verlag Enzyklopädie Langenscheid.

Hopf, J.-M., Bayer, J., Bader, M., & Meng, M. (1998). Event-related brain potentials and case information in syntactic ambiguities. *Journal of Cognitive Neuroscience, 10,* 264–280.

Hummel, J. E., & Holyoak, K. J. (1997). Distributed representations of structure: A theory of analogical access and mapping. *Psychological Review, 104,* 427–466.

Inoue, A., & Fodor, J. D. (1995). Information-paced parsing of Japanese. In R. Mazuka & N. Nagai (Eds.), *Japanese sentence processing* (pp. 9–63). Hillsdale, NJ: Erlbaum.

Jackendoff, R. (1972). *Semantic interpretation in generative grammar.* Cambridge, MA: MIT Press.

Jackendoff, R. (2002). *Foundations of language.* Oxford, England: Oxford University Press.

Jurafsky, D. (2003). Probabilistic modelling in psycholinguistics: Linguistic comprehension and production. In R. Bod, J. Hay, & S. Jannedy (Eds.), *Probablistic linguistics* (pp. 39–96). Cambridge, MA: MIT Press.

Just, M. A., Carpenter, P. A., Keller, T. A., Eddy, W. F., & Thulborn, K. R. (1996, October 4). Brain activation modulated by sentence comprehension. *Science, 274,* 114–116.

Kaan, E., Harris, A., Gibson, E., & Holcomb, P. (2000). The P600 as an index of syntactic integration difficulty. *Language and Cognitive Processes, 15,* 159–201.

Kaan, E., & Swaab, T. (2003). Repair, revision, and complexity in syntactic analysis: An electrophysiological differentiation. *Journal of Cognitive Neuroscience, 15,* 98–110.

Keller, F. (2000). *Gradience in grammar: Experimental and computational aspects of degrees of grammaticality.* Unpublished doctoral dissertation, University of Edinburgh, Edinburgh, Scotland.

Keller, F., & Alexopoulou, T. (2001). Phonology competes with syntax: Experimental evidence for the interaction of word order and accent placement in the realization of information structure. *Cognition, 79,* 301–372.

Keller, T. A., Carpenter, P. A., & Just, M. A. (2001). The neural bases of sentence comprehension: A fMRI examination of syntactic and lexical processing. *Cerebral Cortex, 11,* 223–237.

Kempe, V., & MacWhinney, B. (1999). Processing of morphological and semantic cues in Russian and German. *Language and Cognitive Processes, 14,* 129–171.

Kempen, G., & Harbusch, K. (2003). An artifical opposition between grammar and frequency: Comment on Bornkessel, Schlesewsky, and Friederici (2002). *Cognition, 90,* 208–210.

Kempen, G., & Harbusch, K. (2005). The relationship between grammaticality ratings and corpus frequencies: A case study into word order variability in the midfield of German clauses. In S. Kepser & M. Reis (Eds.), *Linguistic evidence: Empirical, theoretical, and computational perspectives* (pp. 329–349). Berlin, Germany: Mouton de Gruyter.

Kibrik, A. (1997). Towards a comprehensive relational typology. *Linguistic Typology, 1,* 279–346.

Kim, A., & Osterhout, L. (2005). The independence of combinatory semantic processing: Evidence from event-related potentials. *Journal of Memory and Language, 52,* 205–225.

Kiparsky, P. (1989). *Agreement and linking theory.* Unpublished manuscript, Stanford University, Stanford, CA.

Knoeferle, P., Crocker, M. W., Scheepers, C., & Pickering, M. J. (2005). The influence of immediate visual context on incremental thematic role assignment: Evidence from eye-movements in depicted events. *Cognition, 95,* 95–127.

Knoeferle, P., Habets, B., Crocker, M. W., & Münte, T. F. (2005). *The influence of depicted events during spoken language comprehension: Evidence from ERPs.* Poster presented at the 18th annual City University of New York Conference on Human Sentence Processing, Tucson, AZ.

Kroger, J. K., Sabb, F. W., Fales, C. L., Bookheimer, S. Y., Cohen, M. S., & Holyoak, K. J. (2002). Recruitment of anterior dorsolateral prefrontal cortex in human reasoning: A parametric study of relational complexity. *Cerebral Cortex, 12,* 477–485.

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4,* 463–469.

Kutas, M., & Hillyard, S. A. (1980, January 11). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207,* 203–205.

Kutas, M., Van Petten, C., & Kluender, R. (in press). Psycholinguistics electrified II (1994–2005). In M. A. Gernsbacher & M. Traxler (Eds.), *Handbook of psycholinguistics* (2nd ed.). New York: Elsevier.

Lamers, M. A. J. (2001). *Sentence processing: Using syntactic, semantic and thematic information* (Vol. 33). Groningen, the Netherlands: Groningen Dissertations in Linguistics.

Leuckefeld, K. (2005). *The development of argument processing mechanisms in German: An electrophysiological investigation with school-aged children and adults.* Leipzig, Germany: MPI Series in Human Cognitive and Brain Sciences.

Lewis, R. L., & Vasishth, S. (2005). An activation-based model of sentence processing as skilled memory retrieval. *Cognitive Science, 29,* 1–45.

MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review, 101,* 676–703.

MacWhinney, B. (1999). The emergence of language from embodiment. In B. MacWhinney (Ed.), *The emergence of language* (pp. 213–256). Mahwah, NJ: Erlbaum.

MacWhinney, B., & Bates, E. (Eds.). (1989). *The crosslinguistic study of sentence processing.* New York: Cambridge University Press.

MacWhinney, B., Bates, E., & Kliegl, R. (1984). Cue validity and sentence interpretation in English, German and Italian. *Journal of Verbal Learning and Verbal Behavior, 23,* 127–150.

MacWhinney, B., & Pléh, C. (1998). The processing of restrictive relative clauses in Hungarian. *Cognition, 29,* 95–141.

Makeig, S., Westerfield, M., Jung, T. P., Enghoff, S., Townsend, J., Courchesne, E., et al. (2002, January 25). Dynamic brain sources of visual evoked responses. *Science, 295,* 690–694.

Matzke, M., Mai, H., Nager, W., Rüsseler, J., & Münte, T. F. (2002). The costs of freedom: An ERP study of non-canonical sentences. *Clinical Neurophysiology, 113,* 844–852.

McElree, B. (1993). The locus of lexical preference effects in sentence comprehension. *Journal of Memory and Language, 32,* 536–571.

McElree, B., & Griffith, T. (1995). Syntactic and thematic processing in sentence comprehension. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 134–157.

McRae, K., Ferretti, T. R., & Amyote, L. (1997). Thematic roles as verb-specific concepts. *Language and Cognitive Processes, 12,* 137–176.

Mecklinger, A., Schriefers, H., Steinhauer, K., & Friederici, A. D. (1995). Processing relative clauses varying on syntactic and semantic dimensions: An analysis with event-related potentials. *Memory and Cognition, 23,* 477–494.

Neville, H. J., Nicol, J., Barss, A., Forster, K., & Garrett, M. F. (1991). Syntactically based sentence processing classes: Evidence from event-related potentials. *Journal of Cognitive Neuroscience, 6,* 233–255.

Newman, S. D., Just, M. A., Keller, T. A., Roth, J., & Carpenter, P. A. (2003). Differential effects of syntactic and semantic processing on the subregions of Broca's area. *Cognitive Brain Research, 16,* 297–307.

Nichols, J. (1986). Head-marking and dependent-marking grammar. *Language, 62,* 56–119.

Nunez, P. L. (1981). *Electric fields of the brain: The neurophysics of EEG.* New York: Oxford University Press.

Osterhout, L., & Holcomb, P. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31,* 785–806.

Osterhout, L., & Holcomb, P. (1993). Event-related potentials and syntactic anomaly: Evidence of anomaly detection during the perception of continuous speech. *Language and Cognitive Processes, 8,* 413–437.

Osterhout, L., & Mobley, L. A. (1995). Event-related brain potentials elicited by failure to agree. *Journal of Memory and Language, 34,* 739–773.

Ott, M. (2004). *Verarbeitung von variierenden Animatheitsmerkmalen: Eine Studie zum Animatheitseinfluss bei nicht ambig kasusmarkierten W-Fragen im Deutschen* [Processing varying animacy features: A study on the influence of animacy in unambiguous wh-questions in German]. Unpublished master's thesis, University of Potsdam, Potsdam, Germany.

Pesetsky, D. (1994). *Zero syntax.* Cambridge, MA: MIT Press.

Phillips, C., Kazanina, N., & Abada, S. H. (2005). ERP effects of the processing of syntactic long-distance dependencies. *Cognitive Brain Research, 22,* 407–428.

Picton, T. W. (1993). The P300 wave of the human event-related brain potential. *Journal of Clinical Neurophysiology, 9,* 456–479.

Primus, B. (1999). *Cases and thematic roles.* Tübingen: Niemeyer.

Pritchett, B. L. (1988). Garden path phenomena and the grammatical basis of language processing. *Language, 64,* 539–576.

Pritchett, B. L. (1992). *Grammatical competence and parsing performance.* Chicago: University of Chicago Press.

Pustejovsky, J. (1995). *The generative lexicon.* Cambridge, MA: Massachusetts Institute of Technology Press.

Rakison, D. H., & Poulin-Dubois, D. (2001). Developmental origin of the animate–inanimate distinction. *Psychological Bulletin, 127,* 209–228.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372–422.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior, 22,* 657–673.

Röder, B., Stock, O., Neville, H., Bien, S., & Rösler, F. (2002). Brain activation modulated by the comprehension of normal and pseudo-word sentences of different processing demands: A functional magnetic resonance imaging study. *Neuroimage, 15,* 1003–1014.

Roehm, D. (2004). *Waves and words: Oscillatory activity and language processing.* Unpublished doctoral dissertation, University of Marburg, Marburg, Germany.

Roehm, D., Bornkessel, I., Haider, H., & Schlesewsky, M. (2005). When case meets agreement: Event-related potential effects for morphology-based conflict resolution in human language comprehension. *Neuroreport, 16,* 875–878.

Roehm, D., Bornkessel, I., & Schlesewsky, M. (in press). The internal structure of the N400: Frequency characteristics of a language-related ERP component. *Chaos and Complexity Letters.*

Roehm, D., Schlesewsky, M., Bornkessel, I., Frisch, S., & Haider, H. (2004). Fractionating language comprehension via frequency characteristics of the human EEG. *Neuroreport, 15,* 409–412.

Rosch, E., & Mervis, C. B. (1975). Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology, 7,* 573–605.

Rösler, F., Friederici, A. D., Pütz, P., & Hahne, A. (1993). Event-related brain potentials while encountering semantic and syntactic constraint violations. *Journal of Cognitive Neuroscience, 5,* 345–362.

Rösler, F., Pechmann, T., Streb, J., Röder, B., & Hennighausen, E. (1998). Parsing of sentences in a language with varying word order: Word-by-word variations of processing demands are revealed by event-related brain potentials. *Journal of Memory and Language, 38,* 150–176.

Sauerland, U., & Gibson, E. (1996). *Case matching and relative clause attachment.* Paper presented at the 11th Annual City University of New York Conference on Human Sentence Processing, New Brunswick, NJ.

Scheepers, C., Hemforth, B., & Konieczny, L. (2000). Linking syntactic functions with thematic roles: Psych-verbs and the resolution of subject-object ambiguity. In B. Hemforth & L. Konieczny (Eds.), *German sentence processing* (pp. 95–135). Dordrecht, the Netherlands: Kluwer.

Schlesewsky, M. (1997). *Kasusphänomene in der Sprachverarbeitung. Eine Studie zur Verarbeitung von kasusmarkierten und Relativsatzkon-*

struktionen im Deutschen [Case phenomena in language processing: A study on the processing of case marking and relative clause constructions in German]. Unpublished doctoral dissertation, University of Potsdam, Potsdam, Germany.

Schlesewsky, M., & Bornkessel, I. (2003). Ungrammaticality detection and garden path strength: A commentary on Meng and Bader's (2000) evidence for serial parsing. *Language and Cognitive Processes, 18,* 299–311.

Schlesewsky, M., & Bornkessel, I. (2004). On incremental interpretation: Degrees of meaning accessed during sentence comprehension. *Lingua, 114,* 1213–1234.

Schlesewsky, M., Bornkessel, I., & Frisch, S. (2003). The neurophysiological basis of word order variations in German. *Brain and Language, 86,* 116–128.

Schlesewsky, M., & Friederici, A. D. (2003). Sentence processing, mechanisms. In L. Nadel (Ed.), *Encyclopedia of cognitive science* (Vol. 3, pp. 1149–1155). New York: Nature Publishing Group.

Schriefers, H., Friederici, A. D., & Kühn, K. (1995). The processing of locally ambiguous relative clauses in German. *Journal of Memory and Language, 34,* 499–520.

Scott, G. (1978). *The Fore language of Papua New Guinea.* Canberra, Australia: Pacific Linguistics.

Scott, S. K., & Johnsrude, I. S. (2003). The neuroanatomical and functional organization of speech perception. *Trends in Neurosciences, 25,* 100–107.

Sekiyama, K., Kanno, I., Miura, S., & Sugita, Y. (2003). Auditory-visual speech perception examined by fMRI and PET. *Neuroscience Research, 47,* 277–287.

Sereno, S. C., & Rayner, K. (2003). Measuring word recognition in reading: Eye movements and event-related potentials. *Trends in Cognitive Sciences, 7,* 489–493.

Silverstein, M. (1976). Hierarchy of features and ergativity. In R. M. W. Dixon (Ed.), *Grammatical categories in Australian languages* (pp. 112–171). Atlantic Highlands, NJ: Humanities Press.

Smolensky, P., & Stevenson, S. (2005). Optimality in sentence processing. In P. Smolensky & G. Legendre (Eds.), *The harmonic mind: From neural computation to optimality-theoretic grammar.* Cambridge, MA: MIT Press.

Staub, A., & Rayner, K. (in press). Eye movements and on-line comprehension processes. In M. G. Gaskell (Ed.), *The Oxford handbook of psycholinguistics.* Oxford, England: Oxford University Press.

Steinhauer, K., Alter, K., & Friederici, A. D. (1999). Brain potentials indicate immediate use of prosodic cues in natural speech processing. *Nature Neuroscience, 2,* 191–196.

Steinhauer, K., Mecklinger, A., Friederici, A. D., & Meyer, M. (1997). Wahrscheinlichkeit und Strategie: Eine EKP-Studie zur Verarbeitung syntaktischer Anomalien [Likelihood and strategy: An ERP study on the processing syntactic anomalies]. *Zeitschrift für Experimentelle Psychologie, 44,* 305–331.

Stevenson, S., & Smolensky, P. (2006). Optimality in sentence processing. In P. Smolensky & G. Legendre (Eds.), *The harmonic mind: From neural computation to optimality-theoretic grammar. Volume II: Linguistic and philosophical implications* (pp. 307–338). Cambridge, MA: MIT Press.

Stromswold, K., Caplan, D., Alpert, N., & Rauch, S. (1996). Localization of syntactic comprehension by positron emission tomography. *Brain and Language, 52,* 452–473.

Sturt, P., & Crocker, M. W. (1996). Monotonic syntactic processing: A cross-linguistic study of attachment and reanalysis. *Language and Cognitive Processes, 11,* 449–494.

Thompson-Schill, S. L., Bedny, M., & Goldberg, R. F. (2005). The frontal lobes and the regulation of mental activity. *Current Opinion in Neurobiology, 15,* 219–224.

Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences USA, 94,* 14792–14797.

Townsend, D. J., & Bever, T. G. (2001). *Sentence comprehension: The integration of habits and rules.* Cambridge, MA: MIT Press.

Ueno, M., & Kluender, R. (2003). Event-related indices of Japanese scrambling. *Brain and Language, 86,* 243–271.

Ullman, M. T. (2001). A neurocognitive perspective on language: The declarative/procedural model. *Nature Reviews Neuroscience, 2,* 717–726.

Ullman, M. T. (2004). Contributions of memory circuits to language: The declarative/procedural model. *Cognition, 92,* 231–270.

van den Brink, D., & Hagoort, P. (2004). The influence of semantic and syntactic context constraints on lexical selection and integration in spoken-word comprehension as revealed by ERPs. *Journal of Cognitive Neuroscience, 16,* 1068–1084.

Van Valin, R. D., Jr. (2005). *Exploring the syntax-semantics interface.* Cambridge, England: Cambridge University Press.

Van Valin, R. D., Jr., & LaPolla, R. (1997). *Syntax: Form, meaning and function.* Cambridge, England: Cambridge University Press.

Vosse, T., & Kempen, G. A. M. (2000). Syntactic assembly in human parsing: A computational model based on competitive inhibition and lexicalist grammar. *Cognition, 75,* 105–143.

Weber, A., Grice, M., & Crocker, M. W. (2006). The role of prosody in the interpretation of structural ambiguities: A study of anticipatory eye movements. *Cognition, 99,* B63–B77.

Weckerly, J., & Kutas, M. (1999). An electrophysiological analysis of animacy effects in the processing of object relative sentences. *Psychophysiology, 36,* 559–570.

Wright, T. M., Pelphrey, K. A., Allison, T., McKeown, M. J., & McCarthy, G. (2003). Polysensory regions along lateral temporal regions evoked by audiovisual speech. *Cerebral Cortex, 13,* 1034–1043.

Wunderlich, D. (1997). Cause and the structure of verbs. *Linguistic Inquiry, 28,* 27–68.

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