The Neuronal Reality of the Nominal Hierarchy: fMRI Observations on Animacy in Sentence Comprehension

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The possibilities are numerous

once we decide to act and not react.

George Bernard Shaw

1. Introduction

Animacy makes a fundamental contribution to the categorization of everyday experiences. In this way, the differentiation between *'animate'* and *'inanimate'* entities is important for the identification of potentially more or less causative characters and may be carried out by using several modalities. In contrast to inanimate characters, animates are able to move willfully and make noise which can be detected visually, tactually and also auditorily. While movements and sounds play a role in the processing of animacy in humans and animals, animacy is also a decisive feature in language, which is exclusive to humans. Strikingly, the differentiation between animate and inanimate entities is of crucial importance within the whole domain of higher cognitive abilities, hence rendering animacy one of the most important concepts in higher cognition.

Cross-linguistic research revealed a three-tiered animacy hierarchy ranking at least humans over animals and animals over inanimates. The consequences of this animacy hierarchy are reflected by different linguistic properties depending on the language under consideration. In some languages, animacy information has an influence on word order (e.g. German, Finnish), in others case marking is morphologically determined by this feature and an effect of animacy on sentence interpretation can be observed (e.g. Fore, Hindi). Consequently, these observations of a widespread influence of animacy give rise to the assumption that "animacy is a universal conceptual category that exists independently of its realization in any particular language" (Comrie, 1989, p. 186).

The aim of the present thesis is to shed light on the impact of animacy on sentence processing in German. Although animacy is a purely semantic feature, an influence of this parameter on syntactic structure has been observed such that animate arguments should precede inanimate arguments within the German middle field (e.g. *Gestern wurde dem Redakteur der Artikel präsentiert;* yesterday was [the editor]$_{\text{A-OBJ}}$ [the article]$_{\text{I-SUBJ}}$ presented). Since German is a language with flexible word order, the order of the two arguments can also be changed, as demonstrated in the sentence *Gestern wurde der Artikel dem Redakteur präsentiert;* yesterday was [the article]$_{\text{I-SUBJ}}$ [the editor]$_{\text{A-OBJ}}$ presented. Although both sentences are grammatically correct, the linearization of arguments within the latter sentence is unexpected with respect to animacy. Nevertheless, this sentence reflects the preferred subject-before-object order which is violated in the first example. These examples clearly demonstrate that an investigation of the influence of animacy in the linearization of arguments requires a differentiation of word order changes on account of this semantic feature and word order changes that must be attributed to the influence of further linearization principles.

Besides the influence of animacy on the linearization of arguments, this feature is also interesting from a relational point of view. The most natural kind of a transitive sentence comprises an information flow from the causer of an event which is high in animacy to the argument that is lower in animacy and agency. Besides this unmarked transitive sentence structure, German also allows for an asymmetrical and therefore less “natural“ distribution in which either both arguments are animate (*Gestern hat der Redakteur den Mitarbeiter entdeckt*, yesterday has [the editor]$_{\text{A-SUBJ}}$ [the colleague]$_{\text{A-OBJ}}$ discovered) or the assignment of animacy is even completely reversed (*Gestern hat der Artikel den Redakteur überrascht*, yesterday has [the article]$_{\text{I-SUBJ}}$ [the editor]$_{\text{A-OBJ}}$ surprised). However, such asymmetrical distributions are supposed to result in deviations from the unmarked transitive sentence structure indicating that the relation between sentential arguments at least partially depends on their animacy.

After previous behavioral and neurophysiological data provided evidence for an influence of animacy in syntactic processing the present work aims to examine neuroanatomical correlates of this semantic feature. This thesis reports three experiments investigating both the influence of animacy on the linearization of word order and its relational effect in sentence processing.

This thesis essentially consists of two parts. The first part (chapters 1 to 4) summarizes content and tenor of the whole dissertation, ranging from an introduction to the theoretical background on word order variation in German to a discussion and interpretation of the neuroanatomical findings on animacy in syntactic processing within the present work. The second part (chapters 5 to 8) comprises three articles, each of which presents the results of one neuroimaging study in the context of word order variations and the impact of animacy on German sentence comprehension.

In chapter 2, an overview of principles from different linguistic domains determining the linearization within the German middle field will be given (section 2.1). Since the separate consideration of these linearization principles suggests the necessity of a ranking of the rules on the one hand and interactions between several rules on the other, the following section (2.2) involves an introduction into theoretical approaches attempting to formalize the influence of the individual rules on the markedness of sentence structures. Section 2.3 outlines previous empirical findings on word order variation subdivided into behavioral, neurophysiological and neuroanatomical data. The particular role of animacy as a universal semantic feature in a wide range of languages will be pointed out from a theoretical perspective in section 2.4, before section 2.5 highlights the influence of this parameter in sentence comprehension by discussing its neuroanatomical correlates. Finally, chapter 3 attempts to embed the findings on animacy in syntactic processing into the context of theoretical linguistic approaches and discusses these data against the background of neurocognitive models on sentence comprehension.

As already mentioned above, the second part of the present thesis comprises three articles reporting the results of three neuroimaging studies on mechanisms underlying sentence comprehension in German. Experiment 1 (chapter 6) is concerned with linguistic prominence and Broca's area by investigating the influence of animacy as a linearization principle in nominative-dative structures. Experiment 2 (chapter 7) focuses on the role of the posterior superior temporal sulcus in the processing of unmarked transitivity by using sentence material with either one animate and one inanimate argument or two animate arguments. Experiment 3 (chapter 8) concentrates on the impact of pronouns, which are generally assumed to be high in animacy, in word order variation and provides a new perspective on the language-specific function of Broca's Area.

2. An Overview

Sentence comprehension is influenced by a number of factors and requires a linking between different linguistic domains. While it is undisputed that a successful interpretation of a sentence requires the mapping from the form, which is reflected by word order and morphology, to the meaning of the sentence, the mechanisms underlying the linking between these two domains are controversially discussed at present. Which linguistic rules determine the processing of sentences to what extent? How fast are specific cues from the syntactic, semantic or phonological domain processed? Where does the processing of different linguistic features take place? The following sections will concentrate on exactly these questions, focusing on the effects of word order variations and the role of animacy in sentence comprehension.

2.1 Language-specific linearization rules

In many languages the linear position of an argument in a sentence correlates strongly with its syntactic function. Considering English declarative sentences, a strict word order can be found in which the first argument is always the subject. In contrast, German is regarded as a language with a flexible word order which is determined by certain principles. Although there is a preference to interpret the sentence-initial argument as the subject in German (e.g. Bader & Meng, 1999), the decisive factor in the assignment of grammatical functions and participant roles is the morphological case-marking which can override the preferred reading. Nevertheless, the word order is not completely free and German has specific principles determining the linear ordering of arguments in the clause.

Violations against these rules lead to an unexpected sentence structure which will be referred to as a "marked" structure in the present work.[1]

According to the theory of topological fields, which was initially formulated by Drach (1937), the left boundary of the so-called middle field in German starts immediately after the position of the sentence-initial complementizer (e.g. *dass*, "that") or the finite verb in the second position (e.g. *hat*, "has") while the right boundary ends before the position of the clause-final participle, infinitive, or particle (see also Wöllstein-Leisten et al., 1997; Meibauer et al., 2002). The sentence in example 1 indicates the middle field of a German sentence by delimiting it with vertical bars:

1) Dann hat | der Lehrer dem Schüler den Tisch | gezeigt.
   then has [the teacher]$_S$ [the student]$_{IO}$ [the table]$_{DO}$ shown
   'Then the teacher showed the student the table.'

In the following, an introduction into the principles governing the linearization of arguments in the German middle field will be given. These linearization phenomena were initially observed in everyday language use and then derived from the perspective of different grammatical theories. In the next section, I will mainly focus on two descriptive approaches, a classical attempt within the framework of generative grammar (Chomsky, 1965) as formulated by Lenerz (1977) and an attempt on the basis of generalized phrase structure grammar (GPSG, going back to Gazdar & Pullum, 1981, 1985) which was presented by Uszkoreit (1986). These two approaches not only lead to overlapping but also to partially diverging assumptions with respect to decisive

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[1] The term "markedness" was first introduced by Trubetzkoy (1931) and Jakobson (1932) who used it to specify phonological and semantic distinctions. With regard to a syntactic structure, markedness means that the sentence needs a constraining context and cannot be uttered "out of the blue" (Siwierska, 1988). Consequently, sentences that can occur in many different contexts can be viewed as less marked than sentences that can only occur in a few contexts (Höhle, 1982). Since the term "markedness" has been used in a wide range of linguistic contexts (e.g. more difficult, more complex, less frequent) over the past years, Haspelmath criticizes its unprepossessed use by saying "markedness lost its association with a particular theoretical approach and became established as an almost theory-neutral everyday term in linguistics" (Haspelmath, 2006, p. 26). Accordingly, he suggests to replace it with a more general term, namely "abnormality". Within the present work, I will adhere to the term markedness as defined by Siwierska and Höhle, because abnormality does not seem to satisfy the description of different phenomena of word order variation following language-specific linearization rules in German.

linearization principles. Within generative grammar, language is assumed to have two representational levels: (a) a deep structure, which is also called the basic word order on an abstract structural level because it directly represents semantic relations between the single constituents of a sentence; and (b) a surface structure, which is derived from the deep structure by the application of specific transformational rules (e.g. Wh-movement: Move the Wh-phrase to the beginning of the sentence as is shown in *where did he go*) and hence represents the structure of the actual verbalization of a content.

In accordance with classical approaches, Lenerz (1977) situates his linearization rules at the level of phrase structure rules which describe the syntactic structure of a sentence by breaking it down into phrasal categories (e.g. noun phrase, verb phrase) and lexical categories (e.g. noun, verb). This author describes phenomena of word order variation in German by relying on the grammatical functions of sentential arguments (e.g. subject defined by the nominative, indirect object defined by the dative, direct object defined by the accusative).

In contrast, Uszkoreit (1986) situates his linearization rules above phrase structure rules in embedding his assumptions in GPSG, a unification-based grammar in which a syntactic representation is described as a phrase structure tree on one level. This phrase structure tree has non-terminal nodes representing specific feature structures and constitutes a complex rule system determining the well-formedness of a sentence structure. With regard to linearization rules, Uszkoreit distinguishes immediate dominance rules (ID) determining the hierarchical sentence structure and linear precedence rules (LP) that restrict the linearization of arguments in a sentence.

In sum, both approaches are descriptive. Accordingly, there is a strong consistency in terms of the predicted linearization principles, which is independent of the underlying theory.

2.1.1 Subject > indirect object > direct object

A transitive German sentence with a verb like *zeigen* (show) contains three arguments of the verb, a subject and two objects. The basic and therefore unmarked word order of such a sentence is widely assumed as depending on syntactic functions, the lexical entry of the verb and/or thematic roles of the arguments (Lenerz, 1977; Reis, 1987; Hoberg, 1981; Uszkoreit, 1986). Assuming that syntactic functions adopt a primary position, two principles determining the linear ordering of the arguments are important initially: First, the subject should precede the object. Second, if there are two objects the indirect object, the dative argument, should precede the direct object, namely the accusative argument. In this respect, a sentence like the one in example 1 has an unmarked word order, whereas all possible permutations of the three non-pronominal noun phrases within this sentence lead to marked structures as shown in example 2 below.[2]

2) a. #Dann hat der Lehrer den Tisch dem Schüler gezeigt.
   then has [the teacher]$_{S}$ [the table]$_{DO}$ [the student]$_{IO}$ shown
   b. #Dann hat dem Schüler der Lehrer den Tisch gezeigt.
   then has [the student]$_{IO}$ [the teacher]$_{S}$ [the table]$_{DO}$ shown
   c. #Dann hat dem Schüler den Tisch der Lehrer gezeigt.
   then has [the student]$_{IO}$ [the table]$_{DO}$ [the teacher]$_{S}$ shown
   d. #Dann hat den Tisch der Lehrer dem Schüler gezeigt.
   then has [the table]$_{DO}$ [the teacher]$_{S}$ [the student]$_{IO}$ shown
   e. #Dann hat | den Tisch dem Schüler der Lehrer | gezeigt.
   then has [the table]$_{DO}$ [the student]$_{IO}$ [the teacher]$_{S}$ shown
   'Then the teacher showed the student the table.'

The sentences in example 2 illustrate the flexible word order in the German middle field and thereby indicate that, although these sentence structures are marked, they remain grammatical. Lenerz (1977) predominantly focuses on grammatical functions and grammatical relations between indirect object and direct object or between subject and objects and, thereby assumes two basic principles underlying the order of these constituents.

The relevance of grammatical functions in word order variations is further supported by more stylistic tendencies. Following an elementary law of Behaghel (1909) an influence of *heaviness* (*"Gesetz der wachsenden Glieder"*) on the sentence-level is proposed. With respect to the verb complements this implies that the more substantial and meaningful an information is the higher its tendency to occur towards the end of a sentence. If an indirect object is modified by a relative clause, it is therefore

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[2] In the following, marked sentences are assigned a "#" and ungrammatical sentences a "*".

licensed to occur towards the end of the sentence. Otherwise, the indirect object is assumed to be less important than the direct object since a deletion of the dative often allows for a possible interpretation of the sentence while a deletion of the accusative does not (Behaghel, 1932). This law is directly associated with a more stylistic principle, the so-called *"Satzklammerbedingung"*, stating that sentences should never end on a weak constituent, and might also have an influence on the linearization of arguments. Subsequent considerations led to the widely accepted dissociation between old or given contents, which were equated with the *"Thema"* preceding new information, namely the *"Rhema"* (Danes, 1967)[3]. Thus, the "*Thema > Rhema"* principle affects the order of constituents with a simultaneous consideration of pragmatical information, e.g. context, and is also subsumed under the term "communicative dynamism" (Firbas, 1964). Using a question test (see also Danes, 1970; Hatcher, 1956) Lenerz (1977) investigated the linear order of indirect object (IO) and direct object (DO) and demonstrated that sentences with an IO preceding the DO are less restricted than sentences with the reversed order since the IO in the initial position even allows a violation of the *"Thema > Rhema"* principle as is shown in example 3 below.

3) Wem hat der Schüler den Füller gezeigt?
   to whom has the student the pen shown
   'To whom did the student show the pen?'
   a. Der Schüler hat dem Lehrer den Füller gezeigt.
      the student has the teacher$_{[RH/IO]}$ the pen$_{[TH/DO]}$ shown
   b. Der Schüler hat den Füller dem Lehrer gezeigt.
      the student has the pen$_{[TH/DO]}$ the teacher$_{[RH/IO]}$ shown
      'The student showed the teacher the pen.'

[3] Old information is also considered as the background while new information can be termed focus (see Meibauer et al., 2002, pp. 240-242; Fokus-Hintergrund-Gliederung).

4) Was hat der Schüler dem Lehrer gezeigt?
   what has the student the teacher shown
   'What did the student show to the teacher?'
   a. Der Schüler hat dem Lehrer den Füller gezeigt.
      the student has the teacher$_{[TH/IO]}$ the pen$_{[RH/DO]}$ shown
   b. #Der Schüler hat den Füller dem Lehrer gezeigt.
      the student has the pen$_{[RH/DO]}$ the teacher$_{[TH/IO]}$ shown
      'The student showed the teacher the pen.'

Example 4 indicates that sentences with a DO > IO order in which the DO is additionally the rheme are allowed in less contexts and are therefore regarded as marked (see also Wöllstein-Leisten et al., 1997). Accordingly, influences from the information structure of a sentence also indicate the preferred IO > DO order. The order of subject and object will be referred to in detail in section 2.1.4 since it is somewhat more dependent on the type of verb.

The linearization rule SU > IO > DO clearly shows that Lenerz (1977) directly implements his principles on the level of phrase structure rules and relies on grammatical functions for his description of word order variations.

Instead, Uszkoreit (1986) implemented his linearization rules above the level of phrase structure since he assumes structurally independent principles which allow him to formulate grammars for word order on the basis of morphological features and thematic roles. In this respect, a language with a relatively free word order has less LP rules compared to a language with a very strict word order. For German, Uszkoreit assumed a complex LP rule which is based on thematic roles rather than on grammatical functions (see section 2.2).

2.1.2 Pronominal > non-pronominal

While SU > IO > DO is regarded as the basic word order within sentences with non-pronominal noun phrases, the unmarked word order changes in sentences containing only pronominal noun phrases.

Example 5 shows that the direct object should precede the indirect object if the arguments are pronominal (see also Lenerz, 1977):

5) a. Vielleicht hat er es ihm gezeigt.
perhaps has $he_{[P/S]}$ $it_{[P/DO]}$ $him_{[P/IO]}$ shown
b. #Vielleicht hat er ihm es gezeigt.
perhaps has $he_{[P/S]}$ $him_{[P/IO]}$ $it_{[P/DO]}$ shown
'He perhaps showed it to him.'

This deviating unmarked linearization is structurally defined and must be attributed to a strong rule that seems to be generated from grammatical properties of pronouns (Bierwisch, 1963; Reis, 1987).[4] Beyond this criterion pronominal constituents should always precede non-pronominal noun phrases and should therefore occur at the beginning of the middle field independent of their grammatical function. The so-called "Wackernagel Position" at the left edge of the German middle field can only be filled by pronominal noun phrases that must occur in the initial argument position (Wackernagel, 1892). Linguistic observations indicate that this principle even overrules the subject-before-object principle as demonstrated in example 6:

6) a. Dann hat ihm der Lehrer den Stift gezeigt.
then has $he_{[PIO]}$ the $teacher_{[S]}$ the $pen_{[P/DO]}$ shown
'Then the teacher showed him the pen.'
b. #Dann hat dem Schüler der Lehrer den Stift gezeigt.
then has the $student_{[IO]}$ the $teacher_{[S]}$ the $pen_{[DO]}$ shown
'Then the teacher showed the student the pen.'

While in example 6b an initial non-pronominal object leads to a marked sentence structure, in sentence 6a the object is licensed to precede the subject on account of the pronominal status of the object in the initial position. The pronoun-first

[4] Indeed, within verbal utterances even the following linearization can be observed *Pia sagte, dass es er ihm gezeigt hatte* (Pia said that $[it]_{P\text{-}DO}$ $[he]_{P\text{-}S}$ $[him]_{P\text{-}IO}$ shown has). This phenomenon must rather be attributed to cliticization of the unstressed accusative pronoun *es* to the preceding complementizer *dass* on account of phonological reduction.

rule is a strong rule mostly assumed to result in a fixed order of constituents, which means that a SU > IO > DO order in 6a would yield an ungrammatical or at least highly unexpected structure. Non-pronominal noun phrases should never precede subject pronouns or pronouns which can be stressed respectively.

Uszkoreit (1986) considers a phonological constraint for this phenomenon and assumes phonological heaviness to be responsible for the ordering of pronominal and non-pronominal arguments in a sentence. Pronouns are phonologically weaker than non-pronominal noun phrases and should therefore precede them. This is in line with the heaviness principle revealing that longer and more complex elements should occur towards the end of a sentence (Lenerz, 1977; Behaghel, 1909; Pechmann et al., 1996).[5]

2.1.3 Definite > indefinite

At first sight, the following principle appears to be closely related to the “Thema > Rhema” principle: Definite noun phrases should precede indefinite ones. Mostly a definite article is chosen if one can assume that something is already known but, nevertheless, there is no direct linking between these two principles since a thematic noun phrase can also be found with an indefinite article and definite noun phrases can also have a rhematic function as is shown in example 7a (see also Lenerz, 1977).

7) Wem hat der Lehrer einen Platz gezeigt?
   to whom has the teacher a seat shown
   ‘To whom did the teacher show a seat?’
   a. Der Lehrer hat dem Schüler einen Platz gezeigt.
      the teacher has the student$_{[IO/DEF]}$ a seat$_{[DO/INDEF]}$ shown
   b. #Der Lehrer hat einen Platz dem Schüler gezeigt.
      the teacher has a seat$_{[DO/INDEF]}$ the student$_{[IO/DEF]}$ shown
   c. Der Lehrer hat einem Schüler einen Platz gezeigt.
      the teacher has a student$_{[IO/INDEF]}$ a seat$_{[DO/INDEF]}$ shown

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[5] However, the heaviness principle would probably suggest a DO > S > IO ordering of the sentence in example 5a, since the pronoun *es* is even phonologically weaker than the others. In this way, the heaviness principle cannot always explain unmarked orderings of non-pronominal and pronominal noun phrases.

d. #Der Lehrer hat einen Platz einem Schüler gezeigt.
   the teacher has a seat$_{[DO/INDEF]}$ a student$_{[IO/INDEF]}$ shown
   'The teacher showed a/the student a seat.'

8) Wem hat der Lehrer den Platz gezeigt?
   to whom has the teacher the seat shown
   'To whom did the teacher show the seat?'
   a. Der Lehrer hat dem Schüler den Platz gezeigt.
      the teacher has the student$_{[IO/DEF]}$ the seat$_{[DO/DEF]}$ shown
   b. Der Lehrer hat den Platz dem Schüler gezeigt.
      the teacher has the seat$_{[DO/DEF]}$ the student$_{[IO/DEF]}$ shown
   c. Der Lehrer hat einem Schüler den Platz gezeigt.
      the teacher has a student$_{[IO/INDEF]}$ the seat$_{[DO/DEF]}$ shown
   d. Der Lehrer hat den Platz einem Schüler gezeigt.
      the teacher has the seat$_{[DO/DEF]}$ a student$_{[IO/INDEF]}$ shown
      'The teacher showed a/the student the seat.'

The examples in 7 and 8 demonstrate that sentences with an indirect object preceding a direct object allow more unmarked sequences with regard to variations of definiteness than sentences with a direct object preceding the indirect object. The structures in 7b and 7d involve an indefinite direct object in the initial position and are therefore marked while the sentences in 7c and 8c with an initial indefinite indirect object are unmarked.

While the definiteness principle is sensitive for the linearization of direct and indirect object as well as for the sequencing of subject and indirect object it shows no influence with respect to the linearization of subject and direct object (see example 9a/b):

9) a. Möglicherweise hat ein Lehrer den Schüler gesehen.
      probably has a teacher$_{[IO/INDEF]}$ the student$_{[DO/DEF]}$ seen
   b. #Möglicherweise hat den Schüler ein Lehrer gesehen.
      probably has the student$_{[DO/DEF]}$ a teacher$_{[IO/INDEF]}$ seen
      'A teacher probably saw the student.'

In this way, violations of this principle do not always lead to marked structures[6]. Uszkoreit (1986) addresses the influence of definiteness only on the verge of his assumptions in summarizing it under a more general rule stating that focused constituents should follow other constituents. This principle comprises several regularities bearing a pragmatic status (e.g. known information should precede unknown information; the topic should precede other constituents; the focus tends to follow other constituents; definite noun phrases should precede indefinite noun phrases). Thus, Uszkoreit considers the influence of definiteness from a more pragmatic point of view.

In contrast, Diesing (1992) treats determiners at the level of the formal representation of the logical structure of a sentence, namely its logical form (LF), which is derived from the surface structure. This assumption is related to Lenerz' approach (1977) interpreting the rule definites > indefinites as a syntactic principle which affects phrase structure rules (for further information on indefinites see Diesing, 1992).

2.1.4 Thematically higher-ranked > thematically lower-ranked

So far, primarily syntactic principles have been discussed but an important point regarding the linearization in the German middle field is also the linking to semantic representations of the arguments involved in a sentence. The above mentioned preferred word order (subject > object) is only unmarked if it goes in line with the hierarchy of participant roles specified in the lexical entry of the verb. The thematic hierarchy principle states that thematically higher-ranked arguments (AGENT-like/ACTOR) should precede thematically lower-ranked arguments (PATIENT-like/UNDERGOER) (for further information on hierarchical dependencies between different thematic roles see Van Valin & LaPolla, 1997; Jackendoff, 1972; Primus, 1997; Dowty, 1991).

[6] Since the experimental studies reported in this thesis only include visual stimuli the influence of intonation will not be considered here (for a discussion of the interaction between intonation, definiteness, and thema-rhema see Reis, 1987).

Considering German, there are active verbs assigning the AGENT-role to the subject of the sentence (see example 10), but there are also object-experiencer verbs that specify the thematically higher-ranked role for the object of the sentence (see example 11):[7]

10) a. Offensichtlich hat der Lehrer den Schüler erwischt.
obviously has the $\text{teacher}_{\text{[S/Theta1]}}$ the $\text{student}_{\text{[DO/Theta2]}}$ gotten hold of
b. #Offensichtlich hat den Schüler der Lehrer erwischt.
obviously has the $\text{student}_{\text{[DO/Theta2]}}$ the $\text{teacher}_{\text{[S/Theta1]}}$ gotten hold of
'The teacher obviously got hold of the student.'

11) a. Offensichtlich hat der Lehrer dem Schüler gefallen.
obviously has the $\text{teacher}_{\text{[S/Theta2]}}$ the $\text{student}_{\text{[IO/Theta1]}}$ pleased
b. Offensichtlich hat dem Schüler der Lehrer gefallen.
obviously has the $\text{student}_{\text{[IO/Theta1]}}$ the $\text{teacher}_{\text{[S/Theta2]}}$ pleased
'The teacher obviously was appealing to the student.'

Both 10b and 11b sentences have an object in the sentence-initial position but while 10b has a marked structure in which the subject-before-object principle as well as the thematic hierarchy principle are violated, the lexical entry of the verb *gefallen* licenses the permutation in 11b in that it is an attribute of the *Schüler* whether he likes the *Lehrer*. Object-experiencer verbs are often termed "psych-verbs" since they all reflect a mental attitude towards someone or something (Jackendoff, 1972). Lenerz refers to the thematically higher-ranked argument as the "Mitteilungszentrum" of a sentence and, thereby the causer of an event or the person who experiences something (Lenerz, 1977, p. 114).

With regard to the decisive function of thematic roles Uszkoreit (1986) even proposes an analysis in which linear precedence rules are mainly based on thematic roles and are therefore less dependent on grammatical relations or case marking. He assumes that a consideration of the thematic hierarchy (AGENT > GOAL > THEME) is crucial to decide about the markedness of a sentence.

[7] "Theta1" is used for thematically higher-ranked arguments while thematically lower-ranked arguments are assigned "Theta2".

Interestingly, German allows for unmarked permuted structures in which the indirect object precedes the subject (as shown in example 11b) but sentences with a direct object preceding the subject can never be unmarked since the accusative object is always assigned a thematically lower-ranking role than the subject.[8]

2.1.5 Animate > inanimate

A further semantic restriction influencing the argument order in the German middle field reveals that animate arguments should precede inanimate arguments. Unless there is a difference of definiteness between the arguments of a verb, animacy seems to affect the ordering of indirect object and direct object and of subject and indirect object (Heck, 2000; see also von Stechow & Sternefeld, 1988).[9]

12) a. Wahrscheinlich hat der Spickzettel dem Schüler geholfen.
probably has the cheat sheet$_{[S/I]}$ the student$_{[S/A]}$ helped
b. Wahrscheinlich hat dem Schüler der Spickzettel geholfen.
probably has the student$_{[S/A]}$ the cheat sheet$_{[S/I]}$ helped
'The cheat sheet probably helped the student.'

Since the sentences in example 12 involve an inanimate subject and an animate indirect object, both linearizations (12a and 12b) are unmarked, thereby indicating that animacy has an influence on the linearization of arguments. Nevertheless, Lenerz says that animacy only plays a subordinate role in the linearization of arguments and proposes that the unmarked object-before-subject order is accounted for by assuming that the verb takes the object as the center of the event described in that sentence (see Lenerz, 1977, pp. 106-114, for further information about the so-called "Mitteilungszentrum"). Whereas this explanation holds for object-experiencer verbs like *gefallen,* the subject is usually the argument of primary interest in the case of an active verb like *helfen*. Therefore, Heck (2000) proposes animacy as a linearization parameter

[8] Some readers might adduce a sentence like *Johanna behauptete, dass den Schüler der Teufel ritt* (Johanna claimed that [the student]$_{DO/Theta2}$ [the devil]$_{S/Theta1}$ rode) as a counterexample to this statement, but the linearization within this particular example must be attributed to an idiomatic expression and must therefore be seen from a different angle.
[9] In the following, animate arguments are assigned an "A" and inanimate arguments an "I".

which is also confirmed by a further example (13a) including the permutation of indirect object and direct object on account of animacy:

13) a. Dann hat der Polizist dem Lehrer die Fahrerlaubnis entzogen.
then has the officer$_{[S/A]}$ the teacher$_{[IO/A]}$ the driver's license$_{[DO/I]}$ deprived of
b. #Dann hat der Polizist die Fahrerlaubnis dem Lehrer entzogen.
then has the officer$_{[S/A]}$ the driver's license$_{[DO/I]}$ the teacher$_{[IO/A]}$ deprived of
'Then the officer deprived the teacher of the driver's license.'

14) a. Dann hat der Polizist den Schüler dem schlechten Einfluss entzogen.
then has the officer$_{[S/A]}$ the student$_{[IO/A]}$ the bad influence$_{[DO/I]}$ deprived of
b. #Dann hat der Polizist dem schlechten Einfluss den Schüler entzogen.
then has the officer$_{[S/A]}$ the bad influence$_{[DO/I]}$ the student$_{[IO/A]}$ deprived of
'Then the officer deprived the student of the bad influence.'

15) a. Dann hat der Lehrer dem Aquarium das Wasser entzogen.
then has the teacher$_{[S/A]}$ the aquarium$_{[IO/I]}$ the water$_{[DO/I]}$ deprived of
b. #Dann hat der Lehrer das Wasser dem Aquarium entzogen.
then has the teacher$_{[S/A]}$ the water$_{[DO/I]}$ the aquarium$_{[IO/I]}$ deprived of
'Then the teacher deprived the aquarium of the water.'

As demonstrated in the examples in 13 and 14 the verb *"entziehen"* allows different linearizations of indirect object and direct object. If there is an animacy difference between these arguments the animate argument should precede the inanimate one independent of its grammatical function. By contrast, example 15 illustrates that if there is no animacy difference the unmarked word order is given when the indirect object precedes the direct object.

Similar to Lenerz (1977), Uszkoreit (1986) does not attribute a decisive role to the feature animacy itself. Indeed, the influence of animacy is implicitly considered within his thematic hierarchy principle since it is mostly the case that thematically higher-ranked arguments are also animate, and hence precede thematically lower-ranked arguments which are naturally lower in animacy.

In summary, word order variations in the German middle field are subject to a number of principles determining the linearization of arguments. Interestingly, only the subject-before-object principle is purely syntactic in nature. The thematic hierarchy principle must be classified somewhere in between syntax and semantics, since thematic roles are specified in the lexical entry of the verb. In contrast, the other rules arise from different linguistic domains, namely semantics, pragmatics and phonology. While some of these principles have a strong influence on German word order, others only become relevant under particular restrictions. Several approaches have attempted to formalize these principles, of which those of primary importance will be introduced in the following.

2.2 Interactions between linearization rules

The previous discussion of separate linearization principles that determine the argument order within the German middle field made obvious that these principles are not independent of one another. As implicitly indicated in section 2.1, there are interactions between the linearization rules which require a somewhat more formal description of relatively free-word-order structures in German.

2.2.1 Competition-based approaches

In the previous sections, the high flexibility of German word order was described by introducing different influencing principles (as presented in section 2.1) and assuming that not all of these principles are equally important with regard to their influence on the markedness of a sentence (e.g. Lenerz, 1977; Hoberg, 1981; Reis, 1987; Siwierska, 1988). However, although a competition between partially conflicting principles was assumed, it remained unclear how this interaction might take place and in how far an impact of these rules on grammatical theory can be considered.

One of the first approaches to formalize intertwining rules underlying word order variations was suggested by Uszkoreit (1986), who, as briefly outlined in section 2.1.1, initially proposed a mechanism of single ID and LP rules which was then revised with regard to the LP rules. In the revised LP component Uszkoreit proposes combinations of separate LP rules into a complex LP rule[10]:

16) a. ⎧ TR: AGENT < TR: THEME ⎫
    b. ⎪ TR: AGENT < TR: GOAL ⎪
    c. ⎨ TR: GOAL < TR: THEME ⎬
    d. ⎪ FOCUS: - < FOCUS: + ⎪
    e. ⎩ PPRN: + < PPRN: - ⎭

[10] While the present work employs the “>“ sign whenever one argument precedes the other, Uszkoreit (1986) uses “<“ to denote this linearization of arguments.

First of all, the complex LP rule for German in example 16 shows that Uszkoreit (1986), in contrast to Lenerz (1977), mainly focuses on thematic roles (TR) rather than on grammatical functions which is motivated by the major role of thematic hierarchy in the ordering of arguments in German. The present complex LP rule implies the single ordering principles that (a) the AGENT should precede the THEME, (b) the AGENT should precede the GOAL, (c) the GOAL should precede the THEME, (d) focused constituents should follow other constituents, (e) personal pronouns (PPRN) should precede non-pronominal constituents (see also Uszkoreit, 1986, p. 888). Uszkoreit created a complex LP rule (16) since this allows for a conflict between single principles as is indicated by the following example (17) demonstrating the application of this complex rule:

17)	Morgen wird	der Lehrer	dem Schüler	die Note	verraten.
		TR: AGENT	TR: GOAL	TR: THEME	
		FOCUS: -	FOCUS: +	FOCUS: -	
		PPRN: -	PPRN: -	PPRN: -	

tomorrow will the teacher$_{[S]}$ the student$_{[IO]}$ the grade$_{[DO]}$ betray
'Tomorrow the teacher will betray the student the grade.'

Although this sentence violates one rule in that a focused constituent precedes a non-focused constituent it is an unmarked German sentence since the focused element is also the GOAL which is licensed in preceding the THEME. Uszkoreit (1986) proposes different weights for single rules within the complex rule and thereby assumes that this would allow for the combination of weights of observed violated rules to decide about the acceptability of a sentence, e.g. the pronoun rule would receive a high weight while the less decisive focus rule would have a low weight. Following Uszkoreit, the linear precedence rule for pronouns (e) can even license violations of the thematic hierarchy (LP rules a and b) on account of its high weight:

18) Morgen wird	ihm	die Note	ein Lehrer	verraten.
	TR: GOAL	TR: THEME	TR: AGENT	
	FOCUS: -	FOCUS: -	FOCUS: +	
	PPRN: +	PPRN: -	PPRN: -	

tomorrow will him$_{\text{[P-IO]}}$ the grade$_{\text{[DO]}}$ a teacher$_{\text{[S]}}$ betray
'Tomorrow the teacher will betray him the grade.'

This first approach to formalize the mechanisms underlying word order variation gives a good insight into the linearization of arguments and provides an interesting description of the interaction between linearization principles. Nonetheless, it does not clearly specify why the influence of a violation of the pronoun rule is much more decisive than other violations are in that it even yields ungrammatical sentences.

2.2.2 Optimality-theoretic approaches

This section will focus on more recent approaches of embedding linearization principles in a grammatical theory, in which "the satisfaction of one constraint can be designated to take absolute priority over the satisfaction of another", namely optimality theory (Prince & Smolensky, 2004, p. 3). Consequently, hierarchically ranked grammatical constraints are taken as the basis of optimality theory (OT), in which constraints higher in the hierarchy outrank lower ranked constraints. OT therefore enables the determination of the best analysis of an underlying form in terms of grammatical well-formedness. The optimal output not necessarily fulfills all constraints but shows the best violation profile out of a set of candidates. In principle, the constraints are supposed to be universal and developed from generative grammar (Chomsky, 1965). OT considers these constraints in a competition in which language-specific grammaticality differences are captured by different variations in constraint hierarchization. While OT was first applied to phonology and morphology (Prince & Smolensky, 1993) it also allows for an application to other linguistic disciplines like syntax and semantics.

On the basis of OT, Müller (1999) proposed an approach to describe the word order phenomena in the German middle field. The point of origin of this approach is Müller's assumption that the basic clause structure or the deep structure (D-structure) in German relies on grammatical functions and is independent of the verb type. Regarding the German middle field, Müller takes sentences involving exclusively pronouns as shown in example 5a as evidence for an underlying structure in which the subject precedes the direct object and the direct object precedes the indirect object. Müller restricts this D-structure to sentences involving an inanimate indirect object (as already demonstrated in 14a) and argues that sentences with an animate indirect object (see 13a) have the unmarked order S > IO > DO. Accordingly, differences in animacy are assumed to be reflected in the basic word order.

While the permutation or scrambling of non-pronominal arguments in the so-called surface structure (S-structure) is defined as adjunction to the verb phrase (VP) within a subhierarchy, the fronting to the "Wackernagel" position, which is necessary as soon as pronominal arguments are involved, is suggested to take place within a matrix hierarchy. This division into two hierarchies is unavoidable for an optimality-theoretic integration of linearization principles since the crucial optimality-theoretic assumption that a suboptimal candidate is invariably ill-formed has to be modified for scrambling while it can be upheld with regard to the special role of pronouns in German. Hence, the division into a matrix hierarchy and a subhierarchy appears to provide a possible explanation for the strong effect of violations against the pronoun rule that, in contrast to violations against other linearization rules, always result in ungrammatical sentence structures.

Following basic assumptions of optimality-theoretic syntax, one part of grammar, namely GEN, is assumed to consist of equally important and not violable constraints for the generation of candidates, which then undergo a so-called "harmony-evaluation" (H-EVAL) in another part of grammar. In contrast to GEN, the H-EVAL system involves ranked and violable optimality-theoretic constraints, which are supposed to be universal. With regard to the special role of pronouns in the matrix hierarchy Müller focuses on constraints within the H-EVAL system and proposes the following constraint hierarchy determining the linearization of pronouns within the German middle field:

19) PRON-CRIT >> EPP, STAY >> PAR-MOVE

Example 19 shows a hierarchy with four constraints. The highest-ranked constraint is the pronoun criterion (PRON-CRIT), which is a markedness constraint triggering movement of pronominal noun phrases to the “Wackernagel“ position in the S-structure. One further markedness constraint is the extended projection principle (EPP) licensing nominative noun phrases in a position of the matrix hierarchy that even precedes the “Wackernagel“ position. Furthermore, Müller implemented two faithfulness constraints (STAY and PAR-MOVE) for a minimization of syntactic movement operations. The constraint STAY states that overt movement should be prohibited (see Chomsky, 1991, for further information concerning the economy of derivation), while PAR-MOVE stands for parallel movement. As already shown in section 2.1 example 6a, pronouns should precede non-pronominal noun-phrases independent of their grammatical function. Table 1 shows an analysis of two possible S-structures of example 6a in OT:

Candidates	**PRON-CRIT**	**STAY**	**PAR-M**
=> K_1: ihm_1 der Lehrer t_1 den Stift ...		*	*
* K_2: der Lehrer ihm den Stift ...	*		

Table 1: Pronoun fronting.

Table 1 summarizes EPP and STAY under one tie, thereby allowing subject raising to be left aside for the moment.[11] Under these circumstances, K_1 is the optimal candidate since it fulfills the PRON-CRIT, whereas K_2 violates it. K_1 only violates each of the lower-ranked faithfulness constraints STAY and PAR-M once since the pronoun moved to the “Wackernagel“ position crossed a non-pronominal noun phrase.[12] While subject raising over a pronoun is an exception allowed by EPP and does not result in an ungrammatical structure, other suboptimal structures in the matrix hierarchy are ungrammatical in accordance with basic assumptions of optimality theory (see also Müller, 1999, pp.787-793).

[11] Subject raising is demonstrated in the example *Es scheint der Hausmeister in der Werkstatt zu arbeiten* ([it] seems [the caretaker]$_S$ in the garage to work) where *der Hausmeister* is assigned the nominative by the infinitive *zu arbeiten* while it is congruent with the finite verb *scheint*)

[12] With respect to K_1 and K_2, a ranking of STAY and PAR-M is not possible. The hierarchy of these two constraints is adopted from Müller and will not be discussed in further detail within the present work.

With regard to the subhierarchy, Müller (1999) adopts Keller's (1996) suboptimality hypothesis by assuming that suboptimal candidates on this level are not necessarily equally ungrammatical but are rather considered as more marked. Following this idea, suboptimal candidates can be ranked on the basis of their relative grammaticality (see also Keller & Alexopoulou, 2001). Thus, a scrambling criterion (SCR-CRIT) with a number of integrated constraints on the subhierarchy is proposed, thereby dominating STAY and PAR-M while being subordinate to PRON-CRIT (see example 20):[13]

20) PRON-CRIT >> SCR-CRIT (NOM > DEF > AN > FOC > DAT > ADV > PER) >> EPP, STAY >> PAR-MOVE

The constraints within this subhierarchy SCR-CRIT as well as their underlying principles are listed below (Müller, 1999, p. 795):

21) SCR-CRIT: In the VP domain,

a. NOM ("nominative constraint"): [+ nom] > [- nom]
b. DEF ("definiteness constraint"): [+ def] > [- def]
c. AN ("animacy constraint"): [+ animate] > [- animate]
d. FOC ("focus constraint"): [- focus] > [+ focus]
e. DAT ("dative constraint"): [+ dat] > [- acc]
f. ADV ("adverb constraint"): [+ NP] > [+ adv]
g. PER ("permutation constraint", "Anti-Par-Move"): If α c-commands β at level L_n, then α does not c-command β at level L_{n+1}.

[13] Ranking on the matrix hierarchy is indicated by ">>", while Müller (1999) uses the marker ">" for ranking in the subhierarchy.

To demonstrate the application of these rules I will show an analysis of the unmarked sentence in example 1 compared to its permuted versions (see example 2a-e):

Candidates	**SCR-CRIT**							**STAY**	**PAR-M**
	NOM	**DEF**	**AN**	**FOC**	**DAT**	**ADV**	**PER**		
=> K_1: der Lehrer dem Schüler den Tisch									
# K_2: der Lehrer den $Tisch_1$ dem Schüler t_1			*		*		*	*	
# K_3: dem $Schüler_1$ der Lehrer t_1 den Tisch	*							*	*
# K_4: den $Tisch_1$ der Lehrer dem Schüler t_1	*		**		*			*	*
# K_5: dem $Schüler_1$ den $Tisch_2$ der Lehrer t_1 t_2	**		*				*	**	
# K_6: den $Tisch_2$ dem $Schüler_1$ der Lehrer t_1 t_2	**		**		*		*	**	

Table 2: *Word order variation within the middle field of a ditransitive German sentence analyzed in OT.*

In Table 2, K_1 is unmarked since it satisfies all constraints. All of the other candidates involve scrambling and therefore violate STAY. With regard to the degrees of markedness in the group of scrambled candidates, K_2 is the least marked since it only violates AN and DAT within the subhierarchy. K_3 includes a stronger violation in that the dative argument precedes the nominative argument. Then K_4 follows, in which NOM is violated once, AN twice and DAT once, since an inanimate accusative object precedes an animate subject and an animate dative object. K_5 is less marked than K_6 because AN is only violated once and DAT is satisfied, while both these candidates violate NOM twice which leads to the identification of the most strongly marked structures.

Müller's approach (1999) allows for interactions between principles within the subhierarchy SCR-CRIT in that a violation of one principle can be licensed by the resulting satisfaction of another principle, which is higher in the constraint hierarchy.

Candidates	**SCR-CRIT**							**STAY**	**PAR-M**
	NOM	**DEF**	**AN**	**FOC**	**DAT**	**ADV**	**PER**		
=> -> K_1: der Spickzettel dem Schüler			*				*		
=> K_2: dem Schüler$_1$ der Spickzettel t_1	*?							*	*

Table 3: Conflict between two principles in a transitive German sentence analyzed in OT.

Table 3 shows an OT-analysis of the sentences in example 12a and b. There are two candidates involving a conflict, K_1 satisfies NOM but violates AN while K_2 satisfies the latter constraint and violates NOM. Since the violation of NOM is more serious than the violation of AN, K_1 is less marked compared to K_2.

In summary, Müller's approach (1999) describes the ranking and interaction between some of the linearization principles on the subhierarchy and the strength of the pronoun principle on the matrix hierarchy. This two-level approach enables an implementation of these rules in OT by upholding the basic OT-assumption that suboptimal candidates are ungrammatical on the matrix hierarchy level and modifying the interpretation of suboptimality on the subhierarchy level, where suboptimality results in different degrees of markedness.

A further optimality-theoretic approach by Heck (2000) is based on optimization at D-structure rather than assuming S-structure movement from a fixed D-structure as the critical factor for the derivation of unmarked word order. Subject and direct object of a sentence have structural cases, namely nominative and accusative case, leading to a base generation at specific positions within the verb phrase (specifier position for the nominative argument and sister of verb for the accusative argument). In contrast, an indirect object is assigned the dative case, which is a lexical case, and can therefore occur in different positions. The dative argument may either precede the subject, occur between subject and direct object, or follow the direct object. As already described in section 2.1, the linearization principles only affect the ordering of subject and indirect object and of indirect object and direct object while the order of subject and direct object is fixed on account of the structural cases. Heck therefore proposes four hierarchical linearization constraints determining the best position for the base generation of the dative argument relative to other arguments.

22) DEF >> ANIM >> AGENS >> ADJA

The principles DEF and ANIM are comparable with the constraints DEF and AN proposed by Müller, whereas Heck further suggests AGENS and ADJA and not NOM and DAT since he does not assume a fixed D-structure. AGENS says that the thematically higher-ranked AGENT should precede lower-ranked arguments and ADJA determines the position of an argument with a structural case that should occur adjacent to the verb. By relating these principles to the D-structure Heck regards the unmarked word order as the basic word order and, thus, accounts for different possible word orders with one verb (see examples 13a, 14a, 15a). In contrast to scrambling, base generation takes place at the D-structure level and does not result in marked structures. Parallel to Müller, Heck assumes a constraint hierarchy in which, for example, a violation of ANIM has no influence when DEF is satisfied at the same time. The application of a principle only under the circumstance that all dominating principles have no effect is generally known as the *emergence of the unmarked* (McCarthy & Prince, 1994).

While Müller's approach (1999) cannot account for the unmarkedness of an object-first structure involving an object-experiencer verb, Heck (2000) implemented an AGENS constraint that allows for an improved determination of markedness in this special case.

Table 4 demonstrates an application of Heck's approach (2000) to two candidates of a D-structure with the object-experiencer verb *gefallen* (see example 11a/b).[14]

Input: gefall- (Lehrer, Schüler)				
candidates	**DEF**	**ANIM**	**AGENS**	**ADJA**
☞ K_1: dem Schüler der Lehrer				
K_2: der Lehrer dem Schüler			*	*

Table 4: The influence of an object-experiencer verb in a transitive German sentence analyzed in OT.

An interpretation of the AGENS principle in terms of: thematically higher-ranked arguments should precede thematically lower-ranked arguments, shows that the candidate with an object preceding the subject (K_1) is unmarked since the thematically higher-ranked EXPERIENCER (dem Schüler_{IO}) precedes the lower-ranked THEME (der Lehrer_S). Following Heck, K_2 violates AGENS because the thematically lower-ranked subject precedes the object and also violates ADJA since the argument with the lexical case (dem Schüler_{DAT}) is nearer to the verb than the argument with the structural case (der Lehrer_{NOM}). On account of the object in the first position, K_1 would violate the highest constraint (NOM) within Müller's approach and, thus, the phenomenon of unmarkedness of this structure can be better explained by Heck's theory. However, empirical data show that the classification of the subject-first candidate K_2 as marked in comparison to K_1 is also questionable (see section 2.3).

At this point, one further optimality theoretic approach should be mentioned briefly. Within his PhD thesis, Keller (2000) developed a model of gradient grammaticality, namely Linear Optimality Theory (LOT). A decisive difference between his approach and others lies in the fact that Keller not only relies on intuitive informal judgment based on theoretical knowledge about syntactic structures but also provides an empirical motivation for his model. While Müller (1999) dissociates grammaticality and markedness in different hierarchies of German sentences, hard and

[14] Here, I follow Heck by using the sign "☞" for the best candidate. Suboptimal candidates do not receive any marker in Heck's approach.

soft constraints are assumed in the model of gradient grammaticality concentrating on German, English and Greek sentences. Keller's aim was to illustrate crosslinguistic variation, and he created the following constraints, which in essence, are based on the assumptions by Müller and Uszkoreit (1987): NOMALIGN (nominative NPs should precede non-nominative NPs), DATALIGN (dative NPs should precede accusative NPs), ProAlign (pronouns should precede non-pronominal noun phrases), VERBFINAL (the verb should occur in the final position and VERBINITIAL (the verb should occur in the initial position). The two VERB constraints are necessary because Keller considers main clauses requiring the VERBINITIAL constraint as well as subordinate clauses requiring the VERBFINAL constraint. Following Keller the two VERB constraints are context-independent and therefore hard constraints, while all the other above mentioned constraints are interpreted as soft constraints. Consequently, in Keller's approach a violation of the PROALIGN constraint is not more serious than a violation of the NOMALIGN constraint, which is motivated by empirical findings and will be referred to in section 2.3.1. There is a further constraint GROUNDALIGN making different predictions with regard to focus depending on whether the sentence is verb-final or verb-initial. Since this constraint is important for Greek rather than for German it will not be considered here. Keller assessed the ranking of the constraints by investigating the acceptability of different word orders varying in one or more than one violation of single constraints. The degree of unacceptability of the different word orders was then used for planned comparisons, thereby leading to an empirically tested constraint hierarchy, allowing for an estimation of the interaction between different constraints and considering effects of cumulativity for multiple violations. Regarding the possible word orders of a ditransitive German sentence with three arguments (see example 2a-e) Keller's optimality-theoretic approach predicts the same acceptability ranking as Müller's approach does (see Table 2), since NOMALIGN is ranked higher than DATALIGN.

Comparing his own experimental findings to the results of Pechmann and colleagues (Pechmann et al., 1996), Keller even concludes that "animacy fails to have an effect on the order preferences" (Keller, 2000, p. 120) in non-pronominalized word orders, but since the feature animacy in the experiments in question was only varied in the accusative argument, a violation of this principle is always accompanied by an additional variation of the dative-first principle. Sentences like the one in example 12b show that the feature animacy indeed has an influence on word order, which cannot be explained by the constraints proposed by Keller.[15]

To summarize, while previous approaches primarily focused on the importance of different principles determining the linearization in the German middle field without explaining the interaction of these rules, more precise descriptions of free-word-order languages are accomplished by optimality-theoretic approaches. The assumption of constraint hierarchies, in which the principles are ranked with respect to their relevance, allows for a clearer description of the competition between these principles and their interaction. However, for an accurate description of mechanisms underlying word order variation theoretical approaches as well as observations from empirical research are indispensable. The following section will focus on empirical findings related to word order variation.

[15] Further optimality-theoretic approaches to word order variation are suggested by Fanselow and colleagues (1999). These authors consider the influence of linearization constraints on word order variation in sentence processing from a psycholinguistic perspective. On the basis of several self-paced reading studies, they propose an optimality-theoretic parsing mechanism (Fanselow et al., 1999; see also Stevenson & Smolensky, 2006).

2.3 Previous empirical findings on word order variations

As indicated at the end of section 2.2, empirical research has provided new insights into processing mechanisms underlying word order variation. While the first empirical studies in the context of word order variation in German concentrated on the investigation of behavioral data, more recent studies used online methods like event-related potentials to find time-sensitive neurophysiological correlates of underlying processing mechanisms. Within the last decade, functional magnetic resonance imaging (fMRI) was used to receive a high spatial resolution for neuroanatomical correlates of word order variation. In the following, an outline of previous empirical data will be given, subdivided according to experimental methods.

2.3.1 Behavioral data

After many of the theoretical linguistic approaches describing word order variation and its underlying principles in the German middle field relied on introspection, acceptability or grammaticality judgments were used in the majority of empirical studies seeking evidence for linguistic theories, hence allowing for a more objective view. Schütze (1996, p. 2) defines some reasons for the use of acceptability judgments: (a) this task allows for an examination of low frequent sentences, (b) negative evidence is possible within acceptability judgments, (c) the differentiation between errors and grammatical production in natural speech is difficult, and (d) structural properties of language can be examined in isolation. Besides these preferences, he also warns against an uncritical use of experimental data resulting from judgment studies and implicitly suggests the use of standard experimental control techniques to avoid premature interpretations of unreliable data.

Pechmann and colleagues (1996) examined behavioral data on word order variation in German. In a number of experiments, they used different experimental methods to obtain a general idea of mechanisms underlying the relatively flexible word order in German. In the first experimental study, participants had to judge the acceptability of ditransitive active sentences including six different linearizations within the middle field (like those in the examples 1 and 2a-e) on a five-point scale from "absolutely unacceptable" (1) to "absolutely acceptable" (5) and, thus, give a metalinguistic rating. Consequently, the statistical analyses of the ratings revealed a linearization of word orders in terms of acceptability (see example 23) that is also predicted by theories described in section 2.2:

23) S IO DO > S DO IO > IO S DO > DO S IO > IO DO S > DO IO S

Since parameters like definiteness, focus, thematic hierarchy, animacy (subject and indirect object were animate, the direct object was inanimate) and type of noun phrase were kept constant over all word orders, this rating mainly concentrates on the influence of grammatical functions (constraints NOM and DAT in Müller's optimality-theoretic approach, 1999). To ensure its reliability, Pechmann and colleagues furthermore investigated reaction times, latencies in articulation and reproduction of sentences. Thereby, a subject-first preference and a clear disadvantage for the most inacceptable word order were generally found while latencies in articulation were measured without yielding any differences. In sum, the experimental data confirmed the importance of the subject-before-object principle and also provided some evidence for the privilege of the indirect object in comparison to the direct object although this latter result was less decisive.

As already mentioned in section 2.2, Keller (2000) also used acceptability judgments in order to find evidence for his optimality-theoretic approach. He investigated the influence of violations of the NOMALIGN constraint and the DATALIGN constraint on word order variation and found the same acceptability rating for sentences with only animate arguments as Pechmann and colleagues found for the same sentence structures with the only difference of inanimate direct objects. Moreover, Keller studied the influence of the constraint PROALIGN in comparison to the NOMALIGN constraint and found no significant difference between the influence of violations of one or the other constraint, which contradicts Müller's optimality-theoretic approach (1999). In contrast to Müller, Keller therefore takes his empirical data as evidence for viewing both these constraints as equally ranked soft constraints since violations against PROALIGN did not affect acceptability more strongly than NOMALIGN violations.

Kempen and Harbusch (2005, pp. 329 f.) were interested in the "psychological reality" of these constraint rankings and investigated relative corpus frequencies of different word orders. They assumed that structures violating a given constraint are less frequent than linear orderings fulfilling it, constraints that are higher in the constraint ranking are violated less often, sentence structures violating more than one constraint are less frequent than orders violating only one constraint. Frequencies of argument orderings in written and spoken corpora were evaluated with regard to violations of the linearization constraints. The outcome of this frequency test was a “production-based linearization rule“ which is consistent with Müller’s optimality-theoretic approach (1999) in that pronouns should precede non-pronominal noun phrases and occur in the so-called Wackernagel position at the beginning of the middle field, where their order is fixed. The linear order of non-pronominal noun phrases is flexible and only the subject can precede a pronoun. Besides small differences concerning the exact position of a subject when preceding a pronoun and the strictness of constraints, there is a strong relationship between Müller’s theoretical approach and these frequency-related results. Kempen and Harbusch explain the difference between their results and Keller’s empirical approach by a so-called “production threshold“ somewhere between fully acceptable and absolutely unacceptable sentences, which leads to very low or even zero corpora frequencies for structures that are below this value. The authors conclude that discrepancies between their frequency-related approach and Keller’s acceptability-related approach (2000) might be due to “graded ungrammaticality“ that is included in Keller’s assumptions but involves sentence structures non-existent in written and spoken corpus.

Consequently, a combination between linguistic theory, descriptive data like corpus frequencies and empirical data like acceptability ratings might give a first indication for linguistic mechanisms underlying the relatively flexible word order in the German middle field. In sum, the permutation of an unmarked word order always results in a higher linguistic complexity, hence leading to a decrease in acceptability.

Further evidence for an increase of linguistic complexity on account of permutation is given by several reading-time studies in German. Within different sentence structures, readers showed a clear subject-first preference indicated by longer reading-times for more complex object-initial structures. This was shown for unambiguous declarative main clauses (Hemforth & Konieczny, 1993) and also for locally ambiguous embedded clauses (Bader & Meng, 1999), WH-questions (Schlesewsky et al., 2000) and relative clauses (Schriefers et al., 1995). Indeed, the results for locally ambiguous sentence structures might be confounded with processes of syntactic reanalysis on account of case ambiguities and must be interpreted with caution.

For English, Gibson and colleagues (1998) examined center-embedded structures and found a decrease in acceptability dependent on the degree of complexity of a sentence. English has a fixed word order and no morphological case marking. Thus, these findings again must be interpreted carefully in consideration of additional reanalysis phenomena. Nevertheless, the data confirm the correlation between enhanced complexity of sentence structures and decreases in acceptability. Furthermore, this study included an experiment using a self-paced reading task and revealed longer reading times at disambiguating positions for more complex object-extracted relative clauses in comparison to subject-related relative clauses which are less complex (see also King & Just, 1991). Gibson interpreted the longer reading times both in terms of increased processing costs related to difficulties in integrating incoming linguistic elements into the syntactic structure and in terms of additional memory costs arising subject to the number of categories that are required for a completion of the input string as a grammatical sentence structure.

In sum, the behavioral data show that sentences involving deviations from an unmarked word order are typically judged to be less acceptable than sentences without permutations and require longer reading times on account of their higher complexity. On the one hand, these empirical findings might be attributed to the linguistic manipulation, on the other hand, differences in processing costs, acceptability and frequency of simple and complex structures must also be taken into account.

2.3.2 Neurophysiological data

For an online examination of processing mechanisms underlying sentence comprehension event-related brain potentials (ERPs) were examined in order to provide a better dissociation of various interacting processes. Several studies investigating the neurophysiological correlates of word order variation in the German middle field demonstrated that a permuted non-pronominal noun phrase elicits a phasic negativity with a slighty left-lateralized focus between 300 and 450 ms after critical stimulus onset (Rösler et al., 1998; Bornkessel et al., 2002; Schlesewsky et al., 2003).

On account of previous results revealing a negativity over left anterior regions for complex syntactic constructions imposing a larger burden on working memory (Kluender & Kutas, 1993), Rösler and colleagues (1998) attributed their observed negativity to enhanced working memory costs emerging when an argument must be maintained since a direct insertion into its canonical position within the sentence structure is impossible.

First evidence against this interpretation was provided by Schlesewsky and colleagues (2003) who not only examined the processing of word order variations with non-pronominal noun phrases but also varied the type of the initial argument (non-pronominal vs. pronominal noun phrase). While these authors replicated the negativity for non-pronominal objects preceding non-pronominal subjects, no such negativity could be found when an object pronoun preceded the subject. Since in both cases an object precedes the subject, a simple working-memory based account cannot be upheld. Referring to the special status of pronominal arguments in German in that pronouns should always precede non-pronominal arguments within the middle field independent of their grammatical function (see also section 2.1.3), Schlesewsky et al. argued for an interrelation between the observed negativity and a sensitivity of the human parser for markedness elicited by local syntactic violations.

Regarding the possible influence of frequency of different sentence structures on online processing, Bornkessel and colleagues (2002) controlled their experimental conditions for the relative frequency of word orders in the middle field following the complementizer *dass*. The corpus archive 'W-Pub' (Mannheimer Institut für deutsche Sprache) revealed that combinations of a complementizer followed by a nominative marked argument are eight times more frequent than combinations of a complementizer followed by a dative or a complementizer followed by an accusative marked argument, while the latter two sequences occurred equally often. Although a frequency-based account (e.g. Jurafsky, 1996) would have predicted equal processing difficulties for both object-initial conditions, only the accusative-marked objects in the initial position following a complementizer elicited a negativity. These results strengthen the hypothesis of a sensitivity of the human parser to grammatical regularities. Since the condition involving a dative-object following the complementizer and preceding the nominative argument can occur in an unmarked German passive clause, there is no need to interpreting this string as a marked structure locally. Interestingly, the dative-initial condition elicited an early parietal positivity in comparison to the nominative-initial condition at the position of the second argument in the middle field. The authors interpreted this component by assuming that the dative object is first taken as the thematically highest-ranked argument which would be possible in case of a sentence with a passivized verb. However, this argument hierarchy has to be reanalyzed at the position of the following animate nominative argument since the animate nominative is thematically higher-ranked than the dative (Schlesewsky & Bornkessel, 2004).[16]

In summary, neurophysiological data confirmed the assumption that the human parser is sensitive to word order variations. Violations of linearization rules like the subject-before-object principle and also the thematic hierarchy principle not only give rise to longer reading times but also elicit additional processing costs yielding changes in ERPs.

2.3.3 Neuroanatomical data

In order to obtain spatial information about processing mechanisms underlying word order variation, fMRI has been employed as a further promising method. Since this method measures enhanced neural activity via a delayed hemodynamic response, it is not very time-sensitive. Rather, the big advantage of fMRI is its fine-grained spatial resolution.

In the neuroimaging literature, permuted sentence structures have been shown to yield an activation increase in Broca's area and particularly in the pars opercularis of the left inferior frontal gyrus (IFG). Recent studies suggest an engagement of this cortical region in word order variations in the middle field of active German sentences with ditransitive verbs as already demonstrated in examples 1 and 2a-e (Röder et al., 2002; Friederici et al., 2006). These results were consistent with studies investigating neuroanatomical correlates of syntactic complexity in English sentence structures (e.g. Stromswold et al., 1996; Caplan et al., 1998; Ben-Shachar et al., 2003; Ben-Shachar et al., 2004).

[16] Another study investigating word order variations demonstrated that not only the permutation of noun phrases but also the permutation of prepositional phrases (arguments and adjuncts) yields typical ERP-components associated with scrambling (Juranek, 2006).

Röder and colleagues (2002) interpreted their findings in terms of an enhanced syntactic processing load for permuted sentences, which might stem from both syntactic operations (for further information on syntactic transformations see Grodzinsky, 2000) and additional working memory costs (Rösler et al., 1998). Interestingly, the contrast between difficult syntactic sentences *Jetzt wird den Mond dem Forscher der Astronaut beschreiben* (Now will [the moon]$_{DO}$ [the scientist]$_{IO}$ [the astronaut]$_{S}$ describe) and easy syntactic sentences like *Jetzt wird der Astronaut dem Forscher den Mond beschreiben* (Now will [the astronaut]$_{S}$ [the scientist]$_{IO}$ [the moon]$_{DO}$ describe) in their study not only yielded activation in Brodmann's Areas (BA) 44/45 of the left IFG but also showed activation maxima within superior and middle temporal regions (BA 21/22). One reason for this activation might be the parallel investigation of non-semantic sentence conditions, which were not excluded from the data analysis and contained pseudowords. These might possibly have led to a lexical search in left temporal regions.

In contrast to Röder and colleagues (2002), Friederici and colleagues (2006) not only differentiated syntactically easy and difficult sentences but investigated three levels of syntactic complexity. In order to control for effects of cumulativity, a subdivision of conditions into sentences involving either no, one or two permutations was carried out. Prior to the fMRI experiment, the authors conducted a behavioral study including the same stimuli and found a decrease of acceptability as well as an increase of reaction time parallel to the increasing number of permutations, hence replicating behavioral data already described in section 2.3.1. The neuroimaging data confirmed the predictions from the behavioral findings and revealed a parametric complexity effect within the pars opercularis of the left IFG (BA 44) in that the activation within this region increased parallel to the number of word order permutations. The authors associated the pars opercularis activation with linguistic operations necessary for the reconstruction of hierarchical dependencies between arguments within permuted syntactic structures.

All of the investigations of neuroanatomical correlates of word order variations discussed so far concentrated on the influence of violations of the subject-before-object principle. Recently, Bornkessel and colleagues (2005) showed that the pars opercularis of the left IFG is not only sensitive to violations of this purely syntactic linearization principle but also engages in argument hierarchization on account of the thematic hierarchy principle. A comparison of object- and subject-initial sentences with active verbs (e.g. *helfen*, help) revealed a significant activation increase in the pars opercularis for the object-initial sentence structures, and thereby replicated former results. There was no activation difference between object- and subject-initial sentences with object-experiencer verbs (e.g. *auffallen*, notice) assigning a thematically higher role to the object. However, both these conditions yielded a lower degree of activation increase in the pars opercularis in comparison to the object-initial sentences with active verbs but a higher degree of activation when compared with subject-initial sentences with active verbs. Consequently, violations of both linearization principles lead to the highest degree of activation in this cortical region, an intermediate degree of activation was found when either the subject-before-object principle or the thematic hierarchy principle was violated and the lowest degree of activation increase was shown for sentences violating neither of the two principles. These findings support the hypothesis of a language-specific sensitivity of the left IFG in the linearization of sentential arguments. Interestingly, the neuroimaging data of Bornkessel et al. revealed a further cortical region playing a critical role in specific word order variations. Besides the manipulations of verb-type and word order the experiment also contained variations of morphological ambiguity of arguments and the posterior superior temporal sulcus (pSTS) showed an interaction between argument hierarchization demands and morphological ambiguity. These results were consistent with previous results (Friederici et al., 2003; Scott & Johnsrude, 2003; Wright et al., 2003) indicating a role of the pSTS in the mapping between syntactic and semantic information.

With respect to empirical data on word order variation, one further important domain of empirical research should be mentioned, namely lesion-based findings on syntactic movement. This phenomenon is defined in terms of a modification of the hierarchical structure of a sentence determined by a fixed set of derivation rules (deep structure) resulting in the so-called surface structure of the overtly pronounced sentence (for further detail on movement see Chomsky, 1977). Having provided lesion studies of syntactic processing in Broca aphasics (patients with agrammatism), Grodzinsky found characteristic difficulties of his patients when phrasal constituents within a sentential content were moved (via a transformation rule). In his Trace-Deletion Hypothesis (TDH), Grodzinsky (1995; 2000) proposed that a moved constituent must always be linked to its extraction site, namely its canonical position. The linking is assumed to leave a trace at the original position which is regarded as an active category, thereby allowing for an assignment of the thematic role to the moved constituent and checking up on the relation between the trace and its antecedent. On account of the well-known difficulties of Broca's aphasics in the processing of permuted sentences and the assignment of thematic roles in those structures, the TDH approach proposes that traces are deleted from syntactic representations in these patients. Since most of the agrammatic patients have lesions in Broca's region, Grodzinsky directly associated the functional role of this cortical region with the processing of enhanced syntactic complexity elicited by transformations. In his investigations, Grodzinsky further discriminated different types of movements and found performance differences in the detection of violations of constraints on constituent movement (NP or WH; e.g. *The car seems likely to be fast / It seems likely that the car is fast / *The car seems that it is likely to be fast*) and on head (verb) movement (e.g. *The car could have broken down / Could the car have broken down? / *Have the car could broken down?*). While Broca's aphasic patients had comprehension difficulties when noun phrases were moved they succeeded when the position of the verb changed. Binding together informations from neuroimaging data on healthy subjects (e.g. Friederici et al., 2006) and these behavioral data from patients with lesions in Broca's region, Grodzinsky regards Broca's region as being sensitive to the movement of noun phrases and to WH-movement (see also Grodzinsky & Friederici, 2006).

Interestingly, Saffran and colleagues (1998) provided first evidence against the TDH. Examining the role of semantic influences in the assignment of thematic roles, they showed that aphasic patients (with Broca's aphasia or conduction aphasia) exhibited particularly high error rates in plausibility judgments on sentences where semantic constraints (like animacy) conflicted with syntactically based assignments (e.g. *The music was listening to the woman*). Strikingly, the patients were insensitive to these anomalies in permuted and non-permuted sentence structures, hence indicating that aphasic difficulties are not only restricted to sentences involving movement operations. In contrast to Grodzinsky, these authors assume that aphasic difficulties originate from a syntax-based mapping impairment. Thereby two versions of this mapping deficit hypothesis are assumed. On the one hand, missing verb-specific mapping information might lead to problems in assigning thematic roles to the arguments of a verb. On the other hand, the mapping between syntactic constituents and thematic roles might be impaired.

In summary, section 2.3 showed that empirical studies ranging from behavioral measurements of reaction times over ERPs to fMRI can help to evaluate the impact of different principles determining the linearization of arguments within the German middle field. Experimental data provide a first insight into mechanisms underlying the processing of sentences in that they allow for an estimation of temporal and spatial factors of speech processing. Moreover, data from aphasic patients provide interesting findings on syntactic difficulties emerging from lesions in specific brain regions and can help to clarify the functional roles of these areas.

2.4 Animacy from a theoretical perspective

Having provided an overview over the influence of different linearization rules on word order in the German middle field, it is worth focusing on parallels between these principles and those operative in other languages. In this regard, one principle stands out, namely the animacy principle. The feature animacy is of crucial importance in every language and for every culture. This may be attributed primarily to this feature's general relevance in higher cognition. The conceptual distinction between animate and inanimate entities helps to identify the causer of an event and therefore provides important information about agentivity. Considering animacy from a linguistic point of view, a remarkable influence of this feature in a wide range of languages can be found, with interesting differences in its structural impact emerging. In the first instance, these languages have one animacy-based hierarchy in common, which reveals that humans are most prominent in animacy, inanimates are least prominent with regard to this feature and animals are ranked in between these groups. The animacy hierarchy is demonstrated in example 24 (Comrie, 1989; Tomlin, 1986; Croft, 1988):

24) Human > Animal > Inanimate

With regard to transitive sentence structures, this universal hierarchy confirms the animacy principle, which was already shown to affect word order in German in the sense that animate arguments should precede inanimate arguments within the middle field (see section 2.1.5). Following Comrie (1989, p. 128), an interplay between animacy, definiteness and agency should be assumed in that the thematically higher-ranked argument within a transitive sentence construction is typically expected to be high in animacy and definiteness while the thematically lower-ranked argument is naturally also lower in animacy and definiteness. A deviation from this natural kind of a transitive sentence is assumed to yield a deviation from unmarked transitivity.

While animacy affects the linearization of arguments in German, this semantic feature can even influence morphological case marking patterns (e.g. Hindi) and determine the interpretation of arguments (e.g. Fore). In Fore, a Papuan language, case marking interacts with the relative position of the arguments on the animacy-based hierarchy. If an AGENT is higher in animacy than the PATIENT, no case marking is necessary, but in case the AGENT of an event is lower in animacy than the PATIENT it must be overtly coded with the ergative case as is shown in examples 25a/b (Scott, 1978, pp. 100-117):

25)	a.	Yagaa	wá	aegúye
		pig	man.NOM	3SG.hit.3.SG
		'The man kills the pig.'		
	b.	Yagaa-wama	wá	aegúye
		pig-ERG	man.NOM	3SG.hit.3.SG
		'The pig kills the man.'		

In this context, Silverstein (1976; see also Dixon, 1994) extended the animacy-based prominence hierarchy and proposed the so-called 'Nominal Hierarchy', on which pronouns are most prominent (first person pronouns > second person pronouns > demonstratives and third person pronouns) and occupy a position at the left-most end of the hierarchy followed by proper nouns and common nouns again subdivided into human > animate > inanimate items. While participants to the left of the continuum are high in animacy and therefore more likely to be in an agentive function in a sentence, participants on the right-hand side of the hierarchy are lower in animacy, which increases the probability for them to be assigned the PATIENT role. Fore is a split-ergative language in which extra morphological case marking is necessary as soon as a participant appears in an unexpected thematic role as demonstrated in example 25b. With regard to split case marking patterns, DeLancey (1981) describes three types, one of which concerns the animacy of the transitive AGENT (the two further patterns: 'tense/aspect' of the clause and and 'active/stative' split in intransitive clauses will not be discussed in the present thesis). This author's account of split case marking patterns is semantically-based, since he assumes that "the only content of the ergative-marker is the notion of agency" (DeLancey, 1981, p. 630). Considering split case marking patterns from a more psychological point of view, DeLancey particularly points out the attention flow in transitive sentences. Generally, attention flow is assumed to determine the linearization of arguments within a sentence. Relying on suggestions with respect to the prototypical semantic structure of a language (see also Fillmore, 1977a, 1977b) a linguistically unmarked attention flow is proposed to be from an animate AGENT to an inanimate PATIENT.

Languages with overt morphological case-marking in case of unaccustomed roles clearly express markedness in a literal sense. For example, as soon as an inanimate argument within a sentence containing one animate and one inanimate argument receives the thematically higher-ranked role, it requires additional morphological case marking and is therefore obviously marked. Aissen (2003) follows Bossong (1985) in describing this phenomenon as DIFFERENTIAL OBJECT MARKING (DOM) and suggests that the probability for an additional morphological case marking of a direct object increases with increasing prominence of this argument. As previously mentioned, prominence is primarily defined in terms of animacy and definiteness (see Comrie, 1989).

From an optimality-theoretic point of view, the interaction of the animacy hierarchy and transitivity can be dealt with by assuming two constraint hierarchies, one on subjects and one on objects (see Aissen, 2003, for further detail on the optimality-theoretic approach on DOM):

26) a. Subject/Human > Subject/Animate > Subject/Inanimate
    b. Object/Inanimate > Object/Animate > Object/Human

With respect to German, these animacy-related constraints on relative markedness reveal a clear violation of unmarked transitivity for sentences involving an inanimate subject and an animate direct object (27a) and for sentences involving two animate arguments (27b) while the sentence in (27c) shows the most natural and therefore unmarked construction with an animate subject and an inanimate object:

27) a. #Dann hat der Stein den Wanderer getroffen.
    then has the stone$_{[S/I]}$ the hiker$_{[IO/A]}$ hit
    Then the stone hit the hiker.
    b. #Dann hat der Jäger den Wanderer gesehen.
    then has the hunter$_{[S/A]}$ the hiker$_{[IO/A]}$ seen
    Then the hunter saw the hiker.

c. Dann hat der Jäger den Stein gesehen.
then has the hunter$_{[S/A]}$ the stone$_{[IO/I]}$ seen
Then the hunter saw the stone.

In contrast to this classification of unmarked transitivity, Hopper and Thompson (1980) differentiate between sentences of higher or lower transitivity. Following this approach, a sentence involving two animate arguments (see 27b) is defined as being more transitive than a sentence with an animate AGENT and an inanimate PATIENT (as shown in 27c) since an animate PATIENT is regarded as highly individuated and more affected compared to an inanimate one. However, theoretical observations and initial empirical data on the influence of animacy on word order variation (see also section 2.5) encourage me to adopt the view of DeLancey (1981), Aissen (2003), Comrie (1989) and others by assuming that the prototype of a transitive sentence consists of an animate AGENT and an inanimate PATIENT.

Altogether, the examples illustrate a universal influence of animacy as an extra-linguistic concept on syntactic structure. First, there is a decisive semantic difference between animate and inanimate individual arguments in terms of their properties. Second, animacy is important as a relational property in that it shows an influence on the interpretation of the relation between different participants of an event.

2.5 The influence of animacy in sentence comprehension

Descriptive observations substantiate the importance of the semantic parameter animacy and its influence on syntactic structure in a wide range of languages. With respect to the influence of this feature on mechanisms underlying syntactic processing, initial empirical data have shown an effect of violations against the animacy hierarchy and of animacy as a helpful semantic cue in sentence processing respectively.

2.5.1 Background

In a self-paced reading study, Lamers (2001) examined subject-initial Dutch sentences with an embedded clause followed by a main clause and found longer reading times for inanimate-animate orders (e.g. *Dat de kleur de schilder deprimeerde was aan hem te zien*, that [the colour]$_{S\text{-}I}$ [the painter]$_{IO\text{-}A}$ depressed was obvious) in comparison to animate-inanimate orders (e.g. *Dat de bakker het deeg mengde was zjin dagelijks werk*, that [the baker]$_{S\text{-}A}$ [the dough]$_{DO\text{-}I}$ mixed was his daily routine). Evidence for the influence of animacy manipulations on reading times is confirmed by a further behavioral study investigating the processing of subject and object relative clauses in Dutch (Mak et al., 2002). While the comprehension of object relative clauses is usually associated with enhanced processing costs compared to subject relative clauses (see Mecklinger et al., 1995, for evidence in German), Mak and colleagues (2002) varied the animacy of the object and only found a disadvantage in reading times for object relative clauses when both arguments were animate. If the object was inanimate, no reading time differences occurred between both types of relative clauses, hence indicating that animacy information might be used as an early cue in the assignment of thematic roles. A further study from Mak and colleagues (2006) controlled for their hypothesis that there is generally a preference for an object relative clause when the antecedent is inanimate. A comparison of subject and object relative clauses with an inanimate antecedent should therefore have revealed longer reading times (as measured via eyetracking) for the subject relative clause. However, since this was not the case, the results indicated that animacy of the antecedent is not the only decisive factor. While two further reading time experiments manipulating the feature animacy in relative clauses revealed no disadvantages for object relative clauses when the relative clause subject was animate and the head noun was inanimate, disadvantages for object relative clauses were found when the relative clause subject was inanimate and the head noun was animate. These results indicated a partial influence of animacy in sentence processing, and the authors suggested that the interpretation of relative clauses depends on an interplay between animacy, topichood and verb semantics.

Evidence for the use of animacy as a helpful cue in syntactic interpretation was provided by Traxler and colleagues (2005) who conducted eyetracking experiments to investigate the processing of subject and object relative clauses. These data confirmed the findings of Mak and colleagues (2002) in that object relative clauses were easier to process when the sentences started with inanimate objects and contained animate subjects within the relative clause. Longer fixation times indicated that the object relative penalty was stronger when the sentential subject was animate. Interestingly, readers with higher working memory capacities showed stronger benefits of the animacy manipulation than readers with lower working memory capacities. Accordingly, the eye-movement data revealed an interaction of working memory capacity, clause type and animacy.

An interaction of animacy and syntactic structure in the processing of sentences was also shown by Weckerly and Kutas (1999), who manipulated the order of animate and inanimate nouns within object relative clauses and observed a negativity 400 ms post-onset of the inanimate noun (N400) in sentences with an animate-before-inanimate word order (e.g. *The novelist that the movie inspired...*) compared to sentences with the reversed animacy order (*The movie that the novelist praised...*). Since the animate noun is thematically lower-ranked than the inanimate noun in the former case, the authors interpret the N400 as indicating a less natural and therefore less expected situation. Comparable results were presented by Frisch and Schlesewsky (2001), who found an N400 on the second noun phrase of grammatically incorrect German sentences with two subjects when both arguments were animate, while no such effect emerged in the same sentence structure when the second subject was inanimate. This result suggests that the animacy information was used for a ranking of the two arguments with respect to a hierarchy in which AGENTS are more likely to be animate and PATIENTS are more likely to be inanimate as already described in the previous section. Taken together, these neurophysiological results are consistent with observations in theoretical and descriptive research underlining the relational influence of animacy information and indicating deviations from unmarked transitivity. A further hint on the impact of animacy in sentence processing was recently given by Kuperberg and colleagues (2006) in showing that verbs inducing a pragmatic violation but not an (animacy-related) thematic role violation and preceded by an unrelated context and an animate argument (*At breakfast the boys would plant...*) elicited a small P600 (interpreted in terms of reanalysis) and a robust N400. By contrast, verbs eliciting a thematic violation and preceded by an inanimate argument (*At breakfast the eggs would plant...*) yielded robust P600 effects but no N400 regardless of a related or an unrelated context. These ERP effects again revealed an effect of animacy in the processing of relations between a verb and its arguments.

In the neuroimaging literature, the influence of animacy information has primarily been investigated at the word or picture level, while only one recent study examined the neural correlates of this feature in sentence processing. Specifically, Chen and colleagues (2006) investigated object and subject relative clauses and varied the animacy order of the first two arguments. Replicating previous fMRI-studies on relative clauses (e.g. Stromswold et al., 1996), these authors found enhanced activation in the left IFG for object relative clauses (e.g. *The golfer that the lightning struck survived the incident*) in comparison to subject relative clauses (e.g. *The lightning struck the golfer that survived the incident*). Interestingly, this well-known activation increase for object relative clauses was not observed when the animacy order was changed (e.g. *The wood that the man chopped heated the cabin* vs. *The man chopped the wood that heated the cabin*). These results indicate that an association of the activation increase in the left IFG with general structural properties of the examined sentence structures cannot be upheld since Chen and colleagues demonstrated a clear effect of the "noun animacy order".

Considering the fMRI-data on sentence processing, the majority of neuroimaging studies focused on manipulations of syntactic complexity in order to find neural correlates of syntactic processing (see also section 2.3.3). On the one hand, it is beyond dispute that syntactic complexity plays a crucial role in sentence comprehension and is also important for the determination of whether a sentence is easy or difficult to understand. In this way, previous neuroimaging findings on word order variations revealing an activation increase in Broca's region for permuted sentences have been associated with enhanced processing costs for language-related transformation operations (Grodzinsky, 2000). On the other hand, syntactic complexity is often accompanied by other factors influencing the form-to-meaning mapping. This is clearly demonstrated by the empirical data on relative clauses. Although these sentence constructions are generally regarded prime examples eliciting enhanced processing costs on account of their putative syntactic complexity, it was shown that this complexity is also influenced by variations of the non-syntactic feature animacy. As indicated in section 2.1, several language-specific linearization rules determine the word order within the German middle field and besides the syntactic subject-before-object principle there are also restrictions on account of other information types, like semantics and phonology.

2.5.2 The present perspective

The aim of the present work is to shed light on the impact of animacy, a purely semantic feature, on syntactic processing. On the basis of theoretical and first empirical evidence indicating an influence of animacy on morphosyntactic behavior, my intention was to find neuroanatomical correlates for the interaction between animacy and word order variation. Moreover, the relational role of animacy in argument interpretation was examined.

In my first study, I investigated the interaction of three different linearization principles, namely the animacy principle, the subject-before-object principle and the thematic hierarchy principle, in order to dissociate the influence of the animacy principle from other influencing information types (see Experiment 1 in chapter 6). Using passivized ditransitive German sentences, I manipulated the factors animacy (conditions with two animate arguments vs. conditions with one animate and one inanimate argument) and argument order (nominative-dative vs. dative-nominative orders) in the middle field and thereby induced a conflict between the subject-before-object principle and the thematic hierarchy principle. Whenever the subject-before-object principle in these passive structures is fulfilled, the thematic hierarchy principle is violated and vice versa, since the subject is the thematically lower-ranked PATIENT, while the dative object is the thematically higher-ranked RECIPIENT and the AGENT is not realized. Interestingly, sentences with an inanimate subject preceding an animate object (e.g. *Dann wurde der Mantel dem Arzt gestohlen*, then was [the coat]$_{DAT}$ [the doctor]$_{NOM}$ stolen) yielded a significant activation increase in the pars opercularis of the left IFG in comparison to their object-initial counterparts (*Dann wurde dem Arzt der Mantel gestohlen*, then was [the doctor]$_{NOM}$ [the coat]$_{DAT}$ stolen). In contrast, the comparison between the same sentence structures with the only difference that both arguments were animate (e.g. *Dann wurde der Polizist dem Arzt vorgestellt*, then was [the policist]$_{NOM}$ [the doctor]$_{DAT}$ introduced to vs. *Dann wurde dem Arzt der Polizist vorgestellt*, then was [the doctor]$_{DAT}$ [the policist]$_{NOM}$ introduced to) did not reveal activation differences in the pars opercularis. Consequently, an interaction of animacy and argument order was observed in the pars opercularis.

First of all, these data were consistent with the results of a study by Bornkessel and colleagues (2005), which indicated that the pars opercularis activation reflects an interaction of the subject-before-object principle and the thematic hierarchy principle. Regarding the second comparison (conditions without animacy contrast), either the subject-before-object principle or the thematic hierarchy principle was violated within the critical conditions. Indeed, no activation differences were observed within the pars opercularis for this contrast. Accordingly, it was the deviation from the animacy hierarchy (inanimate-before-animate) which led to the activation increase within the pars opercularis. These data clearly reveal an influence of semantic information within the pars opercularis and therefore speak against a purely syntactic transformation-based account of this cortical region.

Since the subject-before-object principle not only states that the nominative should precede the dative argument but also predicts that the nominative should precede the accusative argument (see section 2.1.1), a second fMRI-study investigating the processing of German active transitive structures involving nominative and accusative arguments to control for an influence of case was conducted (see Experiment 2 in chapter 7). As the preferred linearization of sentential arguments S > IO > DO clearly demonstrates, nominative and accusative form the ends of a case hierarchy, thereby indicating that a permutation of the accusative argument into the initial position within the middle field is a strong violation against the subject-before-object principle. Additionally, active nominative-accusative sentences consist of a straightforward mapping between form and meaning in that the nominative is always the thematically higher-ranked argument (apart from one counter-example as already presented in footnote 8). Therefore, word order permutations not only lead to violations against the subject-before-object principle but also to violations against the thematic hierarchy principle.

In Experiment 2, argument order (nominative-accusative vs. accusative-nominative) and animacy (one animate argument and one inanimate argument vs. two animate arguments) were manipulated and animacy was varied in the thematically lower-ranked PATIENT, which was now the object. Interestingly, the results of Experiment 2 revealed no activation differences within the pars opercularis due to animacy. Rather, both object-initial conditions (e.g. *Wahrscheinlich hat den Garten der Mann gepflegt*, probably has [the garden]$_{ACC}$ [the man]$_{NOM}$ taken care of & *Wahrscheinlich hat den Direktor der Mann gepflegt*, probably has [the director]$_{ACC}$ [the man]$_{NOM}$ taken care of) yielded a robust activation increase within the pars opercularis compared to their subject-initial counterparts (*Wahrscheinlich hat der Mann den Garten gepflegt*, probably has [the man]$_{NOM}$ [the garden]$_{ACC}$ taken care of & *Wahrscheinlich hat der Mann den Direktor gepflegt*, probably has [the man]$_{NOM}$ [the director]$_{ACC}$ taken care of), which was independent of the animacy manipulation.

On the one hand, these data are consistent with previous studies showing an effect of word order within the pars opercularis (Röder et al., 2002; Bornkessel et al., 2005; Friederici et al., 2006). On the other hand, the second experiment did not reveal an interaction between argument order and animacy in this cortical region, in contrast to the results of Experiment 1. These different activation patterns must arise from differences in sentence constructions used in the two experiments. While animacy functions as a crucial linearization parameter in nominative-dative structures, in that dative-before-nominative structures are unmarked when the animacy principle is fulfilled, this semantic feature has no influence on the relative positioning of nominative and accusative arguments (see also section 2.1.5). Consequently, permutations of nominative-accusative structures involve a strong violation of the subject-before-object principle and always result in marked sentence structures (see also Schlesewsky & Bornkessel, 2004), which crucially do not improve even when the animacy principle is fulfilled.

Animacy functions as a decisive linearization parameter in the sentence constructions of my first study, while it does not allow for an unmarked object-initial order in the second. Taken together, these results strongly indicate a sensitivity of the pars opercularis to very fine-grained word order distinctions determined not only by syntactic but also by non-syntactic language-specific linearization rules.

Following theoretical assumptions (as introduced in section 2.4), two different aspects of the role of animacy in sentence comprehension must be considered. While the pars opercularis obviously engages in the processing of the order of animate and inanimate arguments this result does not provide information about neural correlates of the role of animacy at a relational-interpretive level. To investigate the relational use of animacy information, an additional comparison was conducted in both experiments by contrasting subject- and object-initial conditions with an animacy contrast against subject- and object-initial conditions without an animacy contrast. While the animacy information may function as an additional semantic cue with regard to the assignment of thematic roles in the processing of the former sentence structures, the latter conditions violate unmarked transitivity in that the thematically lower-ranked argument is not simultaneously lower in animacy. Strikingly, the comparison yielded an activation increase in the posterior portion of the left STS (pSTS) for conditions involving only animate arguments in both studies. On account of the results by Bornkessel and colleagues (2005), who already observed an engagement of this cortical region when a mapping between syntactic and semantic argument hierarchies was not straightforwardly possible, this finding was interpreted in terms of a sensitivity of the pSTS in relational sentence interpretation involving the feature animacy. While it cannot be completely ruled out that the pSTS activation in Experiment 1 is confounded with the crossed linking (the inanimate subject was thematically lower-ranked than the animate object), Experiment 2 clearly indicates a functional correlation between this cortical region and processing mechanisms underlying the relational role of animacy.

The data discussed so far provide strong evidence for an engagement of the pSTS in the language-related use of relational animacy information. As already indicated in section 2.4, animacy is a universal concept which is also important in higher cognition. Notably, parallels between these findings and results from studies investigating the neural correlates of biological motion can be drawn. Enhanced activation of the pSTS is observed when moving objects like hands (Pelphrey et al., 2005; Wright et al., 2003) or interacting point-light dots (Grezes et al., 2001; Saygin, 2006; Schultz et al., 2005) are presented visually. This suggests that the pSTS is involved when agency must be detected in events with more than one participant, a process for which animacy forms an important cue. The present results therefore provide strong evidence for an engagement of this cortical region in the relational processing of animacy in language, which seems to be strongly associated with this region's role in the processing of non-linguistic agency (Frith & Frith, 1999).

The present work comprises a third study, again emphasizing a very particular role of animacy in sentence comprehension (see Experiment 3 in chapter 8). This experiment was, in fact, the first of my three fMRI-studies, and was originally conducted to shed light on the functional role of Broca's region. In previous experiments, an activation increase for permuted sentences in this cortical region was either directly associated with enhanced syntactic working memory costs or interpreted as supporting syntactic movement operations, with each case yielding decreases in acceptability (as already mentioned in section 2.3).

Given that previous findings neither revealed a decrease in acceptability for sentences involving permuted pronouns (Bader & Meng, 1999) nor did permuted pronouns elicit ERP-components typically associated with permutations (Schlesewsky et al., 2003), the special status of pronouns was used in Experiment 3 to allow for a differentiation between competing factors associated with the role of Broca's region in the processing of complex sentences. Independent of their grammatical function, pronouns are licensed to precede non-pronominal arguments within the German middle field (see sections 2.1.3 and 2.2), and permutations of pronouns do not yield a higher degree of markedness although these sentence structures share other domain-general disadvantages of object-initial structures.

In Experiment 3, I therefore manipulated the factors argument order (permuted vs. non-permuted) and type of noun phrase (first noun phrase pronominal vs. first noun phrase non-pronominal) in active ditransitive German sentences. While the activation increase within the pars opercularis for sentences with a non-pronominal object preceding the non-pronominal subject in the middle field (*Dann hat dem Gärtner der Lehrer den Spaten gegeben*, then has [the gardener]$_{IO}$ [the teacher]$_{S}$ [the spade]$_{DO}$ given) in comparison to the non-permuted control condition (*Dann hat der Lehrer dem Gärtner den Spaten gegeben*, then has [the teacher]$_{S}$ [the gardener]$_{IO}$ [the spade]$_{DO}$ given) could be replicated, no analogous activation increase for sentences with a pronominal object preceding the non-pronominal subject (*Dann hat ihm der Lehrer den Spaten gegeben*, then has [him]$_{P\text{-}IO}$ [the teacher]$_{S}$ [the spade]$_{DO}$ given) was found.

Moreover, an additional combined condition (involving permutations of a pronominal indirect object and a non-pronominal direct object as demonstrated in *Dann hat ihm den Spaten der Lehrer gegeben*, then has [him]$_{P\text{-}IO}$ [the spade]$_{DO}$ [the teacher]$_{S}$ given) behaved like the condition with a single permutation of a non-pronominal object with regard to the strength of the pars opercularis activation.

In sum, the pronominal conditions were informative concerning the role of Broca's region in language comprehension. First, the results from Experiment 3 and also the former results from behavioral experiments and ERP-studies investigating pronoun permutations clearly indicated that the role of this cortical region in sentence processing cannot exclusively be explained in terms of an engagement of Broca's region in syntactic working memory. If this association had been right, there should have been no difference between the activation for the conditions involving a pronominal or a non-pronominal permutation. In both conditions the lower-ranked argument of the verb had to be maintained until the higher-ranked argument was processed, a sequence which is often associated with enhanced working memory costs (Kaan & Swaab, 2002; Gibson, 1998).

Second, the findings ruled out a transformation-based interpretation of the activation in the left IFG (Grodzinsky, 2000). If the transformation-based explanation had been right, another result would have been predicted on the basis of linguistic theory. Assuming that pronouns must generally undergo syntactic movement to the Wackernagel position (Haider & Rosengreen, 2003; Müller, 1998), both permuted pronominal conditions (P-OS and P-SO) would have yielded an activation increase in that region, but neither of the two showed an enhanced activation. Even if only the pronominal object in the initial position of the middle field would have theoretically been expected to require a transformation operation, the data would not support the transformation-based account.

Third, the pronoun study showed that the activation in the left IFG cannot be explained with a decrease in acceptability for sentences that are higher in complexity. The significant difference in acceptability which was measured between the combined condition with two permutations and the condition with one permutation was not mirrored by the fMRI-data.

Experiment 3 closes the circle in that it clearly reveals a language-specific function of the pars opercularis in the left IFG in sentence processing and provides converging evidence against other competing accounts assuming a more general cognitive nature of the activation increase. Taken together, the results of Experiment 1 to 3 indicate a sensitivity of the pars opercularis to language-specific linearization rules. Consequently, the present work demonstrates a sensitivity of the pars opercularis to violations of the subject-before-object principle (Experiment 1, 2 and 3), the thematic hierarchy principle (Experiment 1; see also Bornkessel et al., 2005) and the animacy principle (Experiment 1), to which I also attribute the influence of the principle stating that pronouns should precede non-pronominal arguments (Experiment 3).[17] While the subject-before-object principle is purely syntactic in nature, the thematic hierarchy principle must be located somewhere between syntax and semantics, the pronoun principle can, at a first glance, be placed between syntax and phonology and the animacy principle consists of semantic information.

As already discussed in sections 2.1 and 2.2, some of these information types from different linguistic sources are closely related to each other, like the subject-before-object and the thematic hierarchy principle or the animacy principle and the thematic hierarchy principle. Besides the subject-before-object rule, there is one principle showing exceptional consequences for pars opercularis activation, namely the pronoun principle. Violations of the subject-before-object principle are obviously licensed when the pronoun rule is fulfilled. Thus, this principle even overrules the subject-before-object principle in terms of activation patterns in the pars opercularis (see Experiment 3). The special status of pronouns in German has been controversially discussed in theoretical linguistic research, but the present data are compatible with Müller's OT-approach (1999) in which the PRON constraint belongs to the matrix hierarchy and is therefore higher ranking than the NOM constraint as the highest-ranked constraint within the subhierarchy (see section 2.2).

However, the theoretical background of the strong influence of pronouns, which precede non-pronominal arguments independent of their grammatical function, is not entirely clear. Against the background of the present results, the effects are not only interpreted in terms of an argument's syntactic and phonological prominence, but semantic prominence is also regarded as a further decisive factor. As the nominal

[17] Meanwhile, the definiteness principle has also been investigated with respect to its influence on sentence processing patterns in fMRI, thereby providing further converging support for the linearization hypothesis of the pars opercularis function (Bornkessel et al., submitted).

hierarchy in section 2.4 demonstrated, pronouns are classified as being higher in animacy than common nouns. Therefore, the findings of Experiment 3 can also be accounted for in terms of an interplay between syntactic, phonological and semantic information in that not only the pronoun principle but also the animacy principle license the object pronoun to precede the non-pronominal subject within the middle field.

3. Summary and Outlook

The present work highlights the impact of language-specific linearization principles on word order variations in German. On account of its universal properties, one of these principles has previously been widely discussed in theoretical linguistic research whereas there has been only little empirical evidence about the influence of this parameter in syntactic processing. The principle in question is the animacy principle, which states that animate arguments should precede inanimate arguments in the German middle field. This thesis presents neuroanatomical correlates of animacy as a semantic feature in sentence processing. In addition to the influence of the animacy hierarchy on the linearization of animate and inanimate noun phrases, animacy also has an influence on the relation between arguments in sentences. A sentence involving an animate AGENT and an inanimate PATIENT is regarded as instantiating an unmarked transitive relation, while a sentence with two animate arguments has a marked transitive structure, since the relation between the two arguments changes because the thematically lower-ranked argument is highly individuated and also more affected by the event. Accordingly, animacy also affects linking between the syntactic form and the semantic interpretation of a sentence. It shows an influence on linking mechanisms, which are necessary for the assignment of thematic roles to the arguments of the verb.

Regarding the influence of animacy on the linearization of arguments, a sensitivity of the pars opercularis of the left IFG to violations against the animacy principle was demonstrated. Furthermore, the pSTS of the left hemisphere was shown to engage in the processing of unmarked transitivity, which can be attributed to the relational impact of animacy information.

In contrast to former accounts on the functional role of the pars opercularis, which attributed its sensitivity to complex sentence structures in terms of syntactic transformations or syntactic working memory costs, the present thesis provides strong evidence for a language-specific function of this region in the linearization of arguments. Thus, enhanced activation in the pars opercularis was not only found when the subject-before-object principle was violated but also when sentences involved violations against the thematic hierarchy principle, the pronoun principle and the animacy principle. These neuroimaging data clearly reveal an early interaction of syntactic, semantic and phonological information in sentence processing and support the linearization hypothesis of the pars opercularis function.

Undoubtedly, the form-to-meaning mapping is highly complex and depends on different information types, which must be bound together for a successful interpretation of syntactic structures. This is reminiscent of Ray Jackendoff's (2002) theoretical approach, which describes the syntax-semantics interface by assuming a tripartite parallel architecture with parallel representations for syntactic, semantic and phonological information. With respect to sentence processing, information types from different sources are supposed to interact with one another at specific interface levels. In this way, the pars opercularis might be regarded as an interface for the interaction of linearization rules from different linguistic layers.

There have been different approaches to describe the role of Broca's area and particularly the pars opercularis in sentence processing. In section 2.3.3, I introduced the transformation-based account of Grodzinsky (2000). Recently, this account was embedded in a broader theory of syntactic knowledge, which assumes an engagement of this cortical region in the operation MOVE_{XP} (movement of noun phrases or WH-phrases) (Grodzinsky & Friederici, 2006). However, the present data (see Experiments 1-3; see also Bornkessel et al., 2005) clearly indicate that not only constituent movements yield an activation increase in the pars opercularis but also violations against the thematic hierarchy principle and the animacy principle. Considering the approach of Grodzinsky and Friederici it would therefore be necessary to assume an additional dependency relation representing the restrictions of language-specific linearization rules at least for German.

There is also a neurocognitive approach that regards this cortical region as being involved in the unification of linguistic structures (Hagoort, 2005). With respect to syntactic unification, Hagoort proposes stored templates which are associated with individual lexical items and which encode different information types about these items (e.g. grammatical function, word category). Words can be combined to form phrases and phrases to form larger syntactic structures. Thus, unification combines syntactic frames which are assumed to be processed one after the other. Thereby, Broca's region is assumed to subserve syntactic, semantic and phonological unification processes. Indeed, semantic information is implicated here in terms of semantic unification, but first, the approach fails to explain the engagement of the pars opercularis in word order variation in which no templatic differences between object- and subject-initial structures can be assumed, and second, distinctive operations for semantic and syntactic unification operations are proposed. Hagoort assumes different cortical subregions within the left IFG for the different unification operations in proposing that BA 47 and 45 are involved in semantic processing, BA 45 and 44 are sensitive to syntactic operations and BA 44 as well as parts of BA 6 contribute to phonological processing. Although animacy is a semantic feature, the present results do not confirm this distribution. Accordingly, the model cannot account for an influence of animacy on word order variations.

On the basis of studies with Broca's aphasics at the level of word retrieval, Thompson-Schill (2005) suggests a more general cognitive role of this cortical region in controlling selection mechanisms. An investigation of effects of repetition and competition during word generation in an fMRI priming study revealed higher activations in Broca's region when irrelevant information was given compared to priming with relevant information (Thompson-Schill et al., 1999). Enhanced activity was not only found in specific language-related tasks but also in working memory trials when selection of information among competing alternatives was required (Thompson-Schill et al., 1997; Kan & Thompson-Schill, 2004; Thompson-Schill et al., 2002). On account of these data, Thompson-Schill regards Broca's region as subserving selection among competing sources of information. At first sight, this selection-based account seems quite attractive in that enhanced activation in the pars opercularis as a subregion of Broca's area was also found within the present work when language-specific principles were violated, thereby leading to interpretation difficulties. The different linearization principles could be assumed to be in a competition as already proposed in OT-approaches in theoretical linguistic research (see section 2.2), thereby yielding selection difficulties. However, I found differences in the impact of violations against the animacy principle. On the one hand, animacy showed an effect in nominative-dative structures (see Experiment 1), while violations against the subject-before-object principle in nominative-accusative structures revealed no influence of the semantic feature animacy (see Experiment 2). On the other hand, the pronoun principle licensed object-first structures in that no activation increase in the pars opercularis was found and thereby overruled the subject-before-object principle (see Experiment 3), which was also interpreted in terms of an influence of animacy. If the selection-based account was right, animacy should generally have shown an overruling effect. However, the selection-based account of Broca's region appears interesting, but it would be necessary to factor differences in selection strengths into this approach. Furthermore, an interaction of different sources of incoming information should be considered.

In contrast to the widely discussed role of the left IFG in sentence comprehension, the association between pSTS function and syntactic processing is quite new. In their *language processing map*, Grodzinsky and Friederici (2006) assume different phases for the processing of sentence structures. Here, the computation of local phrase structures in phase 1 is followed by phase 2 in which dependency relations are computed (e.g. $MOVE_{XP}$, as previously introduced). Thereafter, the authors propose phase 3 involving processes of syntactic integration which are thought to be subserved by the left posterior superior temporal gyrus (pSTG) and cite different fMRI-studies revealing an enhanced activation of this cortical region when the integration of sentential elements into the syntactic structure is difficult on account of lexical (related to verb complexity) or syntactic restrictions (e.g. Bornkessel et al., 2005). Relying also on ERP-results from patients with posterior lesions in the temporal lobe not showing the typically expected P600 when processes of syntactic integration were required (Kotz & Friederici, 2003; see also Friederici & Weissenborn, in press), Grodzinsky and Friederici assume the pSTG to engage in the integration of lexical and syntactic information. However, as already mentioned before, this neurocognitive model of syntactic processing lacks an explanation for the influence of linearization principles like the animacy principle and the thematic hierarchy principle in phase 2. Furthermore, there are no specific assumptions with regard to activations in the pSTS.

Recently, Bornkessel and Schlesewsky (2006) proposed a neurocognitive model accounting for the impact of different linearization rules and also for the relational influence of animacy in syntactic processing. The so-called *extended argument dependency model* (eADM) is an online model as it can derive neurophysiological and neuroanatomical correlates of mechanisms underlying the processing of verb-argument relations. Within the present work, only a short introduction into this very fine-grained model can be given. Roughly speaking, the model involves three phases of sentence processing out of which one (phase 2) is subdivided into two parts (phase 2a and phase 2b). In phase 1, incoming structures are assigned to syntactic templates (word categories) which, when selected, enter either the verb or the noun phrase pathway in phase 2. At this point, relational aspects of the mapping between syntactic and semantic information come into play. On the one hand, these aspects are established between the arguments (noun phrase pathway), and on the other hand, relations between the verb and its arguments are identified (verb pathway). In phase 3, the authors assume a "generalized mapping" in that the outcome of the noun phrase pathway and the verb pathway flow together and an evaluation of well-formedness takes place.

First, an influence of language-specific linearization rules on syntactic processing is implemented via a computation of prominence in the noun phrase pathway of phase 2b. The detection of violations against single principles might result in an enhanced activation of the pars opercularis depending on the ranking of the violated principle and its interaction with others. Second, the relational influence of animacy on sentence processing which I found in my data can be accounted for in that the verb pathway in phase 2b involves a processing of agreement between the lexical argument hierarchy and the morphosyntactic structure. This latter pathway therefore subserves the identification of possible conflicts between thematic hierarchy and morphosyntactic structure and also accounts for the relational influence of animacy in identifying marked transitive sentence structures, thereby yielding activation increases in the pSTS when violations are detected.

Altogether, the results of the present work indicate that a combination of theoretical linguistic knowledge about syntactic structure and empirical research on sentence processing is very desirable. Consequently, theoretical assumptions about hierarchical rankings of linearization constraints may be helpful for an implementation of these principles in a neurocognitive model while empirical data can provide further information about the ranking of individual constraints. Thereby, the empirical data on the influence of linearization principles on sentence processing clearly point out the necessity of a consideration of the animacy principle and the thematic hierarchy principle as linearization constraints in OT-approaches.

With regard to the ranking of these constraints in OT, further investigations on the influence of these principles and their interaction with others would be helpful. As Experiment 3 demonstrated, the animacy principle can have an overruling effect within the pars opercularis in form of the pronoun first rule which licenses a pronominal object to precede a non-pronominal subject. However, this overruling effect has only been investigated in nominative-dative structures. Since nominative and accusative form the ends of the case hierarchy, it would be interesting to control for the impact of the pronoun principle within permuted nominative-accusative structures (e.g. *Dann hat ihn der Vater dem Sohn gegeben*, then has [it]$_{P\text{-}ACC}$ [the father]$_{SUBJ}$ [the sohn]$_{DAT}$ given). On the one hand, the overruling effect of the pronoun principle licensing pronominal objects to precede non-pronominal subjects might disappear when the subject is preceded by an accusative pronoun, thereby indicating that the influence of animacy depends on the type of violation as already indicated in Experiment 1 and 2. On the other hand, initial accusative-pronouns were shown to behave similarly to initial dative-pronouns in the ERP-study by Schlesewsky and colleagues (2003, see also section 2.3.2). On account of these neurophysiological results, the pronoun principle might generally be expected to license even strong violations against the subject-before-object rule indicating that sentences with an accusative pronoun preceding the non-pronominal subject would behave exactly like sentences with a dative pronoun in the first position in neuroimaging, too. A further fMRI-study on the impact of the type of noun phrase in nominative-accusative constructions might also help to clarify the theoretical background of the pronoun principle and its connection to the animacy principle, which is not yet completely solved.

Another interesting experimental manipulation would be a follow-up study to Experiment 2, thereby investigating the impact of animacy in another type of marked transitive sentence structure with an inanimate but thematically higher-ranked subject followed by an animate and thematically lower-ranked accusative object (*Vielleicht hat der Stein den Schüler getroffen*, probably has [the stone]$_{I\text{-}SUBJ}$ [the scholar]$_{A\text{-}OBJ}$ hit). In terms of the relational influence of animacy, this sentence structure would be expected to yield an analogous activation increase within the pSTS as sentences with two animate arguments compared to unmarked transitive structures. Regarding the linearization of animate and inanimate arguments, there might be an increase within the pars opercularis for this structure compared to the same sentence structure without a violation of the animacy principle (*Vielleicht hat der Schüler den Stein gesehen*, probably has [the scholar]$_{A\text{-}SUBJ}$ [the stone]$_{I\text{-}OBJ}$ seen). Of course this would call for a highly subtle sensitivity of this cortical region to the influence of animacy on word order.

Within the present work, I often referred to an influence of linearization principles which are language-specific in nature. Regarding the universality of the animacy hierarchy, it would therefore be interesting to investigate the neuronal correlates of this semantic feature in other languages. It is predominantly the eADM (Bornkessel & Schlesewsky, 2006) which gives an insight into the potential of cross-linguistic empirical research in that this is the first neurocognitive model providing evidence for unity and diversity in online sentence processing mechanisms over different languages. For example, the influence of animacy as a linearization rule is always assumed to be processed within the 'compute prominence' mechanism investigating the interplay between different linearization rules (prominence hierarchies) within a given sentence. It depends on the given language which further linearization principles from other information types interact with the animacy principle and are therefore crucial for the processing of prominence in this particular language. Since initial ERP-studies on Chinese, which has SOV-constructions like German, also indicate an influence of animacy on syntactic processing, an investigation of the neuroanatomical correlates of animacy in Chinese would be interesting. As already demonstrated in German, two different neuroanatomical regions are supposed to engage in the processing of animacy as a linearization parameter and in the computation of animacy as a relational feature cross-linguistically, namely the pars opercularis of the left IFG and the left pSTS.

Finally, it is important to emphasize that the fMRI-data may, indeed, only be interpreted as neuroanatomical correlates of processing mechanisms. Cortical regions that have been shown to be sensitive to a language-specific principle should never be interpreted as being exclusively specialized for this particular function. The present work demonstrated neither that Broca's region is a specific syntax-module nor that the pSTS solely engages in the processing of relational animacy. Both these cortical regions show sensitivities to other processes in higher cognition. Accordingly, neurolinguistic studies can seek out correlations between the language-specific parameters yielding enhanced activation in a particular cortical region and other processes showing similar activation patterns. As a consequence, a broader understanding of human properties might yield a better classification of specific processing mechanisms underlying language.

4. References

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5. Experimental Studies

Experiment 1: Grewe, T., Bornkessel, I., Zysset, S., Wiese, R., von Cramon, D. Y., & Schlesewsky, M. (2006). Linguistic prominence and Broca's area: The influence of animacy as a linearization principle. *NeuroImage 32*, 1395-1402.

Experiment 2: Grewe, T., Bornkessel-Schlesewsky, I., Zysset, S., Wiese, R., von Cramon, D. Y., & Schlesewsky, M. (accepted). The role of the posterior superior temporal sulcus in the processing of unmarked transitivity. *NeuroImage*.

Experiment 3: 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.

6. Experiment 1: Linguistic Prominence and Broca's Area: The Influence of Animacy as a Linearization Principle

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Previous neuroimaging findings suggest a sensitivity of the pars opercularis of the left inferior frontal gyrus (i.e. a core subregion of Broca's area) to a number of linguistic dependencies governing the linear sequencing of information in a sentence (e.g. subjects should precede objects; the participant role hierarchy should be respected). The present study used event-related fMRI to examine the hitherto untested hypothesis that the violation of a linearization principle that is purely *semantic* in nature (animate arguments should precede inanimate arguments) would also lead to increased pars opercularis activation. To this end, we manipulated the features animacy and argument order in German sentences and found a significant increase of activation in the pars opercularis for a violation of the *animacy principle* even when the other factors mentioned above were controlled for. This result therefore calls for a "supra-syntactic" account of pars opercularis function in the real-time understanding of sentences.

Key words: language comprehension; linearization principles; argument hierarchization; animacy; inferior frontal gyrus, pars opercularis.

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6.1 Introduction

Many neuroimaging studies in the domain of sentence comprehension have undertaken manipulations of syntactic complexity in order to identify brain regions that can be related to syntactic processing. However, while syntactic complexity undisputedly plays an important role in determining how easy or difficult a sentence is to understand, it is generally accepted that this type of complexity is often accompanied by other influencing factors (Jackendoff, 2002). In particular, the mapping from the surface form of a sentence to its associated meaning is not only governed by syntactic factors (e.g. grammatical functions, Chomsky, 1981), but also by semantic information types (e.g. participant roles, Jackendoff, 1972), and phonological restrictions (e.g. accent placement, Büring, 2001). All of these different factors have been shown to influence the linear ordering of constituents within a sentence and, as such, may play a role in determining how the language processing system accomplishes the form-to-meaning mapping. A crucial question is therefore how these different influencing factors may be dissociated from one another and which status should be attributed to them in a neurocognitive model of language comprehension.

The aim of this paper is to investigate the interaction of three linearization principles using event-related functional magnetic resonance imaging (fMRI). In the following, we will therefore firstly introduce the theoretical foundations for the principles to be examined, before turning to previous neurocognitive results related to this question and introducing the design of the present study.

In languages such as English, the only feature specifying syntactic functions of arguments is their linear position in the sentence. Thus, in declarative sentences, the first argument of a sentence will always be the subject. In contrast, other languages deviate from this principle on account of a wide range of further influences on word order. German, for instance, also shows a preference for a subject-analysis of the first participant (argument) of a sentence, this preferred reading can be overridden by unambiguous morphological case marking (e.g. in *Sie wusste, dass dem Studenten die Professoren geholfen hatten*; She knew that the student$_{OBJ}$ the professors$_{SUBJ}$ helped had). Thus, German allows inverse word orders and morphological marking is the decisive factor in the assignment of the participant roles in sentence interpretation.

But what advantage may be gained by allowing object-initial word orders? The simplest answer to this question appears to be that, under certain circumstances, a violation of the *subject-before-object* principle ("syntactic prominence") serves to satisfy other important principles, thereby providing for a straightforward form-to-meaning mapping. Two such "other" principles that are particularly relevant in German are that animate arguments should precede inanimate arguments (henceforth: the *animacy principle*) and that higher-ranking participant roles should precede lower-ranking participant roles (henceforth: the *thematic hierarchy principle*) (see also Wöllstein-Leisten et al., 1997; Lenerz, 1977). When these principles are violated, the complexity of the form-to-meaning mapping increases.

The importance of animacy in this regard does not appear surprising in view of the exceptional role that this feature plays in determining morphosyntactic patterns in a wide range of languages (Comrie, 1989). For example, animacy not only affects morphological case marking patterns (e.g. in Hindi and Russian), but also determines the linear ordering of arguments in certain languages (e.g. Fore, a language of Papua New Guinea). All of these distinctions follow a universal hierarchy of animacy-based prominence, in which humans are most prominent and inanimate objects are least prominent (Tomlin, 1986). Despite the fact that German morphosyntax does not encode animacy distinctions, the application of the animacy hierarchy is nonetheless apparent in the linear ordering of arguments in this language. Thus, the subject-initial embedded clause *Johanna behauptete, dass der Fotoapparat dem Journalisten entrissen wurde* (Johanna claimed that the camera$_{SUBJ+INANIMATE}$ the journalist$_{OBJ+ANIMATE}$ wrested-from was) is less marked when the animate object is placed into a position preceding the inanimate subject *Johanna behauptete, dass dem Journalisten der Fotoapparat entrissen wurde* (Johanna claimed that the journalist$_{OBJ+ANIMATE}$ the camera$_{SUBJ+INANIMATE}$ wrested-from was).[1]

A second linearization principle of comparably undisputed importance is the *thematic hierarchy principle* (the "who is acting on whom" principle). Thus, there is a ranking of *thematic role* prominence, in which thematically higher-ranked (AGENT-like/Actor) arguments always precede lower-ranked (PATIENT-like/Undergoer) arguments (Van Valin and LaPolla, 1997; Jackendoff, 1972). When the thematic

[1] Markedness in this context means that this sentence cannot be uttered "out of the blue". Thus the marked sentence requires a constraining context (Siwierska, 1988).

prominence of the arguments does not coincide with their syntactic prominence (i.e. when the higher-ranking thematic argument is not also the subject of the sentence), this leads to syntactic restrictions in many languages of the world. In English, for example, sentences of this type (e.g. *Bill strikes Harry as pompous.*) cannot undergo passivization (**Harry was struck by Bill as pompous.*) (Jackendoff, 1972, p.45). Like the animacy hierarchy, the thematic role hierarchy finds a direct correlate in word order preferences in German. Therefore, the subject-initial argument order in *Pia glaubte, dass der Dekan dem Professor vorgestellt wurde* (Pia believed that the dean$_{SUBJ+PATIENT}$ the professor$_{OBJ+RECIPIENT}$ introduced was) is more marked than the corresponding object-initial order in which the higher-ranking Recipient precedes the lower-ranking Patient: *Pia glaubte, dass dem Professor der Dekan vorgestellt wurde* (Pia believed that the professor$_{OBJ+RECIPIENT}$ dean$_{SUBJ+PATIENT}$ introduced was). This assumption is theoretically motivated by the well-established hierarchy of thematic roles: Agent > Recipient > Patient (Jackendoff, 1972).

In the neuroimaging literature, word order variations – and particularly violations of the *subject-before-object principle* – have been closely linked to increased activity of Broca's area (i.e. BA44/45). Thus, there is clear evidence that the activation of Broca's area increases as a function of the number of argument permutations and, thereby, of the number of deviations from the base order subject > indirect object > direct object (Fiebach et al., 2004; Röder et al., 2002). This activation increase corresponds to a reduction in sentence acceptability (Bader & Meng, 1999; Gibson, 1998): the more permutations a sentence involves, the less acceptable it is.

On the one hand, this inferior frontal activation in permuted sentences has been related to syntactic transformations (Ben-Shachar et al., 2003; Ben-Shachar et al., 2004; Grodzinsky, 2000). Thus, the higher the number of transformations, the higher the activation of Broca's area. On the other hand, some authors consider the effect to be related to working memory demands, which also increase in parallel to the syntactic complexity (Caplan et al., 2000; Kaan & Swaab, 2002; Müller et al., 2003; Fiebach et al., 2005). These costs may either stem from the (syntactic) requirement to reconstruct an underlying base order (Fiebach et al., 2005) or from the inability to associate an initial object with an appropriate meaning until the verb is encountered (Gibson, 1998; Kaan & Swaab, 2002). In this way, despite their conflicting views on the functional significance of Broca's area activation, these two classes of explanations appeal primarily to the relation between subjects and objects.

Recent findings, by contrast, suggest that a characterization of the function of Broca's area and particularly of the pars opercularis of the left inferior frontal gyrus (IFG) in purely syntactic terms is too narrow. Rather, it has been shown that the activation increase in the pars opercularis that arises from violations of the *subject-before-object principle* can be neutralized when the object-initial ordering allows for other linearization principles to be upheld (Bornkessel et al., 2005; Grewe et al., 2005).

Firstly, Bornkessel et al. (2005) demonstrated an influence of the *thematic hierarchy principle* on the activation of the pars opercularis. These authors found an interaction between this principle and the *subject-before-object principle* such that a violation of neither principle led to the lowest degree of activation, violations of both principles gave rise to the highest degree of activation and a violation of either one principle or the other was reflected in an intermediate degree of activation within this cortical region.

Secondly, Grewe et al. (2005) demonstrated that the pars opercularis is sensitive to a further language-specific principle, which concerns the linearization of pronouns and non-pronominal noun phrases. Following Lenerz (1977), pronouns precede non-pronominal arguments in unmarked German clauses independently of their status as subject or object. This linearization rule is directly reflected in the activation pattern of the pars opercularis, since sentences involving an initial pronominal object, e.g. *Dann hat ihm der Lehrer den Spaten gegeben* (then has him$_{IOBJ}$ the teacher$_{SUBJ}$ the spade$_{DOBJ}$ given), did not show an activation increase in comparison to the control condition with a non-pronominal subject in the first position. By contrast, compared with the control condition object-initial sentences without pronouns showed the well-known activation increase within the pars opercularis.

These results indicate that the activation of the pars opercularis in the processing of argument order variations results from a complex interaction between the *subject-before-object principle* and a variety of further principles. The aim of the present study is to extend these observations by examining the role of animacy as a linearization parameter. As described above, the influence of animacy on morphosyntactic phenomena may arguably be considered the clearest example that a purely semantic feature can modulate the syntactic behavior of a language.[2] Therefore, if animacy also affected the activation pattern of the pars opercularis, this would provide the strongest possible evidence that word order complexity effects in this region cannot be characterized in purely syntactic terms.

Consequently, the design of the present study manipulated the factors argument order (subject-object vs. object-subject) and animacy (animacy contrast vs. no animacy contrast between the two arguments). The resulting four critical conditions are illustrated in Table 1.

Condition	**Example**
OS_I	Dann I wurde I dem Arzt I der Mantel I gestohlen. then was [the doctor]$_{DAT}$ [the coat]$_{NOM}$ stolen 'Then the coat was stolen from the doctor.'
S_IO	Dann I wurde I der Mantel I dem Arzt I gestohlen. then was [the coat]$_{NOM}$ [the doctor]$_{DAT}$ stolen 'Then the coat was stolen from the doctor.'
OS_A	Dann I wurde I dem Arzt I der Polizist I vorgestellt. then was [the doctor]$_{DAT}$ [the policeman]$_{NOM}$ introduced to 'Then the policeman was introduced to the doctor.'
S_AO	Dann I wurde I der Polizist I dem Arzt I vorgestellt. then was [the policeman]$_{NOM}$ [the doctor]$_{DAT}$ introduced to 'Then the policeman was introduced to the doctor.'

Table 1: Critical sentence conditions in the present experiment. Stimulus segmentation is indicated by the vertical bars. Abbreviations used: OS = object-before-subject (permuted); SO = subject-before-object (non-permuted); NOM = nominative; DAT = dative; S_I = inanimate subject; S_A = animate subject.

Crucially, the structures shown in Table 1 allow for a dissociation of the *animacy principle* from the *subject-before-object principle* and the *thematic hierarchy*

[2] Indeed, previous neurocognitive findings provide converging evidence for the importance of animacy in sentence comprehension. On the one hand, Frisch & Schlesewsky (2001) used event-related brain potentials to show that animacy information interacts with case marking in the online computation of a thematic hierarchy. On the other hand, Weckerly & Kutas (1999) argued that animacy modulates the interpretation of subject arguments in English. This finding is paralleled by recent neuroimaging evidence (Chen et al., to appear).

principle. This was accomplished by employing passivized ditransitive structures. These types of sentences induce a conflict between the *subject-before-object principle* and the *thematic hierarchy principle*, because the subject argument is the thematically lower-ranking Patient, while the object argument is the thematically higher-ranking Recipient. (On account of the properties of the passive, the Agent argument is not realized.) With respect to the subject-initial structures, this means that the *thematic hierarchy principle* is violated, while the *subject-before-object principle* is fulfilled. For the object-initial sentences, by contrast, the *thematic hierarchy principle* is fulfilled, but the *subject-before-object principle* is violated. As was shown in Bornkessel et al. (2005), a conflict between these two principles leads to a neutralization of the pars opercularis activation increase for object-initial structures. It is precisely this phenomenon that allows us to isolate possible animacy-induced activation changes within the pars opercularis: while condition OS_I respects the *animacy principle*, this principle is violated in condition S_IO. The interaction of the different linearization principles is summarized in Table 2.

	Subject > Object	**Recipient > Patient**	**Animate > Inanimate**
A. OS_I	-	+	+
B. S_IO	+	-	-
C. OS_A	-	+	+
D. S_AO	+	-	+

Table 2: Linearization rules concerning the critical conditions in the present experiment.

Our hypotheses for the present study are therefore as follows. On the basis of the line of argumentation laid out above, we should observe a clear activation increase within the pars opercularis when the *animacy principle* is violated (i.e. for S_IO vs. OS_I). However, an interpretation of a difference between these two conditions in terms of animacy presupposes that the two conditions without an animacy contrast (S_AO/OS_A) do not differ significantly in this region.

6.2 Materials and methods

6.2.1 Participants

21 students (9 females; mean age 25.19) participated in the fMRI study. All participants were monolingual, native speakers of German, had normal or corrected-to-normal vision, and were right-handed as indicated by a German version of the Edinburgh Inventory (Oldfield, 1971). Informed written consent was obtained from all participants prior to the scanning session.

6.2.2 Materials

The sentence stimuli used in this study consisted of four types of grammatically correct German passive sentences (see Table 1 for one sample set of stimuli). In addition to these critical conditions, there were two types of grammatically incorrect German passive constructions to balance out the acceptability for the behavioral task (see below). Each participant read 34 sentences in each of the conditions. All critical sentences comprised a sentence-initial adverb, followed by a finite auxiliary, two arguments, and a clause-final participle. The ungrammatical fillers were of a similar form as the critical sentences but contained an incorrectly positioned participle. Participants thus read a total of 204 sentences. Additionally, 34 null events (empty trials) were introduced to improve statistical evaluation of the data (Miezin et al., 2000), thus resulting in a total number of 238 trials per participant.

6.2.3 Procedure

All participants read the experimental sentences via LCD goggles (Visuastim; Magnetic Resonance Technology, Northridge, CA). Reading strategies were controlled for by presenting all sentences in a segmented manner. Every segment was presented for 400 ms in the centre of the screen with an interstimulus interval (ISI) of 100 ms (segmentation indicated in Table 1). Each trial began with a presentation of an asterisk (300 ms plus 200 ms ISI) and ended with a 500-ms pause. After this, a question mark signaled to participants that a behavioral response was required. Their task was to judge the acceptability of the preceding sentence. This judgment task was carried out by pressing one of two push-buttons with the right index and middle fingers and the participants were given maximally 2500 ms to respond. The assignment of fingers to acceptable and unacceptable was counterbalanced across participants. The trials were presented with variable onset delays of 0, 400, 800, 1200, or 1600 ms, thereby leading to an oversampling of the actual image acquisition time of 2000 ms by a factor of five (Miezin et al., 2000). Every trial had a length of 8 s, thus resulting in a total measurement time of 32 min, which was separated into two functional runs.

Before entering the scanner each participant completed a short practice session.

6.2.4 fMRI data acquisition

The experiment was carried out on a 3T scanner (Medspec 30/100, Bruker, Ettlingen). Twenty axial slices (19.2 cm FOV, 64 by 64 matrix, 3 mm thickness, 0,6 mm spacing), parallel to the AC-PC plane were acquired using a single shot, gradient recalled EPI sequence (TR 2000 ms, TE 30 ms, 90° flip angle). As the main focus of the experiment was on the activation of pars opercularis of the IFG, we chose to increase the spatial resolution for this region by means of a reduction in slice thickness and spacing. Consequently, a whole-head coverage was not possible and no signal was acquired for regions such as inferior parts of the cerebellum and superior parts of the frontal and parietal lobes. Two functional runs of 484 time points were collected, with each time point sampling over the 20 slices. Prior to the functional runs, 20 anatomical T1-weighted MDEFT (Ugurbil et al., 1993; Norris, 2000) images (data matrix 256x256, TR 1.3 s, TE 10ms) and 20 T1-weighted EPI images with the same geometrical parameters as the functional data were acquired.

6.2.5 fMRI data analysis

The fMRI data were analyzed using the LIPSIA software package (Lohmann et al., 2001). This software contains tools for preprocessing, registration, statistical evaluation and presentation of fMRI data.

First, the functional data were corrected for motion using a matching metric based on linear correlation. To correct for the temporal offset between the slices acquired in one scan, a cubic-spline-interpolation based on the Nyquist-Shannon-Theorem was applied. A temporal highpass filter with a cutoff frequency of 1/112 Hz was used for baseline correction of the signal and a spatial Gaussian filter with 5.65 mm FWHM was applied.

Subsequently, a rigid linear registration with six degrees of freedom (3 rotational, 3 translational) was performed to align the functional data slices onto a 3D stereotactic coordinate reference system. The rotational and translational parameters were acquired on the basis of the MDEFT and EPI-T1 slices to achieve an optimal match between these slices and the individual 3D reference data set. This 3D reference data set was acquired for each subject during a previous scanning session. The MDEFT volume data set with 160 slices and 1mm slice thickness was standardized to the Talairach stereotactic space (Talairach & Tournoux, 1988). The same rotational and translational parameters were normalized, i.e., transformed to a standard size via linear scaling. In a next step, the resulting transformation parameters were applied to the functional slices via trilinear interpolation, so that the resulting functional slices were aligned with the stereotactic coordinate system. This linear normalization process was improved by a subsequent processing step that performs an additional non-linear normalization (Thirion, 1998).

The statistical evaluation was based on a least-squares estimation using the general linear model for serially autocorrelated observations (see also Friston et al., 1995; Worsley & Friston, 1995; Aguirre et al., 1997; Zarahn et al., 1997). The design matrix was generated with a box-car function convolved with the hemodynamic response function. The model equation, including the observation data, the design matrix as well as the error term, was convolved with a Gaussian kernel of dispersion of *4 sec. FWHM* to deal with the temporal autocorrelation (Worsley and Friston, 1995). Thereafter, contrast maps were generated for each subject. As the individual functional datasets were all aligned to the same stereotactic reference space, a group analysis was performed. The single-participant contrast-images were entered into a second-level random effects analysis for each of the contrasts. The group analysis consisted of a one-sample t-test across the contrast images of all subjects that indicated whether observed differences between conditions were significantly distinct from zero (Holmes & Friston, 1998). Subsequently, *t* values were transformed into *Z* scores. To protect against false positive activations, only regions with a *Z* score greater than 3.1 ($P < 0.001$ uncorrected) and with a volume greater than 162 mm^3 (6 measured voxels) were considered (Braver and Bongiolatti, 2002; Forman et al., 1995).

6.3 Results

6.3.1 Behavioral data

For the analysis of the behavioral data, repeated-measures of variance (ANOVAs) were computed using the factors animacy (ANI: I vs. A) and word order (ORDER: SO vs. OS). The probability levels for planned comparisons were adjusted according to a modified Bonferroni procedure (Keppel, 1991).

The mean acceptability rates in the behavioral task were: OS_I (97%); S_IO (93%); OS_A (95%); S_AO (92%). Thus, there were no main effects for the factors ANI and ORDER in the global analysis (ANI ($F(3,60) = 1.98$; $p > .175$); ORDER ($F(3,60) = 1.26$; $p > .292$) and no interaction between these two factors could be found (ANI BY ORDER ($F(3,60) = 1.09$; $p > .308$)).

The reaction times showed the following mean values per condition: OS_I (523 ms); S_IO (556 ms); OS_A (596 ms); S_AO (584 ms). While the global analysis again revealed no significant main effects for the factors ANI ($F(3,60) = 7.94$; $p > .11$) and ORDER ($F(3,60) < 1$), the interaction between both factors was marginally significant (ANI BY ORDER: $F(3,60) = 3.31$; $p = .084$). Planned comparisons for each of the levels of ANI revealed a significant difference between S_IO and OS_I ($F(1,20) = 4.57$; $p < .05$), which resulted from longer reaction times for condition S_IO compared to OS_I. There was no significant difference between the conditions with only animate arguments (S_AO vs. OS_A: $F(1,20) < 1$).

In this way, the reaction time differences confirm the predictions for the experimental manipulation. The violation of the *animacy principle* leads to increased reaction times, while there is no difference between the two conditions without an animacy contrast.

6.3.2 fMRI data

In accordance with our main hypothesis, we first examined the interaction contrast for our two critical factors ((S_IO - OS_I) - (OS_A- SO_A)). This contrast, however, yielded no significant activations at an acceptable significance threshold, possibly due to the very fine-grained linguistic manipulation employed (all critical conditions are highly acceptable and do not give rise to conscious processing difficulty).

On account of our clear prediction with respect to linearization and the pars opercularis, we next conducted a region-of-interest (ROI) analysis in order to test for a possible interaction within the pars opercularis. To this end, we determined the local activation maximum within the pars opercularis from the activation for all four of our critical conditions, i.e. from the contrast between critical conditions and empty trials. In determining local maxima, only activations with a z-value > 3.09 ($p < 0.001$, uncorrected) and a volume of at least 216 mm^3 (8 measured voxels) were taken into account. Local maxima were defined as voxels with the highest z-value exceeding 3.09 within an 8 mm radius. For the ROI analysis, we extracted the time course of the underlying BOLD-response for the local activation maximum within the pars opercularis (-53 9 21) and the 26 adjacent voxels. The percent signal change (relative to the mean signal intensity over all time points per voxel) inside this region was averaged for each condition and participant. The time course of the null events was subtracted from the averaged single-event time courses for the critical sentence conditions (Burock et al., 1998). The averaged time courses (mean percent signal change for a time window from -2 to +2 relative to the maximal signal change per participant and condition), which are visualized in Figure 1, were subjected to a repeated measures analysis of variance (ANOVA) involving the factors word order (ORDER; OS vs. SO) and animacy (ANI; I vs. A). This analysis revealed a clear interaction of ORDER x ANI (F (1,20) = 5.65, $p < .03$). Planned comparisons for each level of ANI showed a significant effect of ORDER for S_IO vs. OS_I (F (1,20) = 25.57, $p < .001$) but no significant difference between the two conditions with only animate arguments ($F<1$).

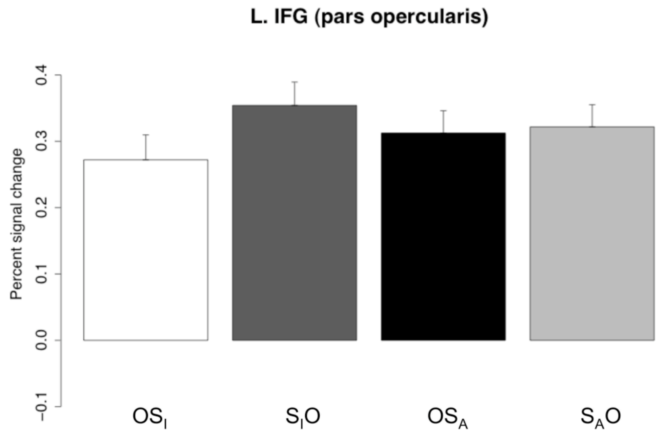

Figure 1: *ROI analysis for the pars opercularis of the left IFG. Average percent signal change (-2 to +2 s relative to the point of maximal signal change) for the activation maximum within this region (-53 9 21) and the 26 adjacent voxels. Error bars indicate the standard error of the mean.*

On the basis of the interaction between word order and animacy obtained in the ROI analysis, we computed a direct contrast between the two conditions involving inanimate subjects in different positions (S_IO vs. OS_I). To ensure that this comparison would not be confounded with reaction time differences (which also contrasted between S_IO vs. OS_I), (z-transformed) reaction times per condition and participant were included in the analysis and modeled as a covariate of no interest. As shown in Figure 2 and Table 3a, this contrast yielded a significant activation within the superior portion of the pars opercularis, with a maximum highly comparable to that examined in the ROI analysis. No other significant activations were observed. To rule out the possibility of false positives, we used a MonteCarlo Simulation (http://afni.nimh.nih.gov/afni/doc/manual/AlphaSim) to dermine the non-arbitrary voxel cluster size. This simulation provides a means of estimating the probality of a false detection of activated clusters (< 0.05) and showed that activations exceeding 5 voxels (135 mm^3) have an alpha error of < 0.01.

Thus, while the activation within the pars opercularis is relatively small (8 voxels), it indeed appears meaningful.[3]

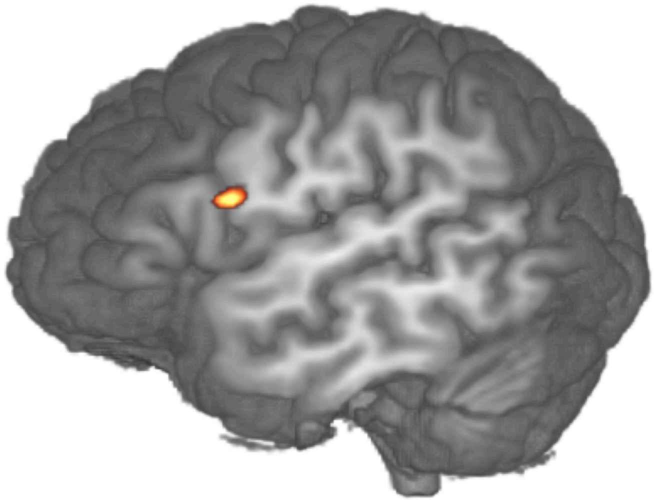

Figure 2: *Averaged activation with a z-value > 3.09 (N = 21) for the contrast between the condition with an inanimate subject preceding an animate object (S_IO) and the condition with an animate object preceding an inanimate subject (OS_I) after the reaction times have been modelled.*

Region	**Talairach coordinates**	**Max. z-value**	**Volume (mm^3)**
L. inferior frontal gyrus (IFG), pars opercularis	-53 6 21	4.01	216

Table 3a: *Talairach coordinates, maximal z-values and volumes of the activated region for the local maxima in the contrast between sentences with an inanimate argument preceding the animate argument (S_IO) and sentences with an animate argument preceding the inanimate argument (OS_I) in an analysis including the mean reaction times per condition and participant as regressors. Only activations with a z-value > 3.09 and a volume of at least 216 mm^3 (8 measured voxels) were considered.*

[3] An additional time course analysis for this activation (conducted in an analogous manner to that described for the ROI analysis above) again confirmed the finding of an interaction between animacy and word order (F (1,20) = 6.17, p < .03). This interaction resulted from a significant difference between the two conditions involving one inanimate argument (F (1,20) = 26.23, p < .001), while the two conditions with only animate arguments did not differ from one another (F<1).

Region	Talairach coordinates	Max. z-value	Volume (mm^3)
L. superior occipital gyrus (19)	-26 -75 18	3.57	270
R. basal ganglia (BG), putamen	28 3 0	3.77	729
L. basal ganglia (BG), putamen	-23 -3 9	3.66	378

Table 3b: *Talairach coordinates, maximal z-values and volumes of the activated region for the local maxima in the contrast between sentences with two animate arguments (S_AO vs. OS_A) in an analysis including the mean reaction times per condition and participant as regressors. Only activations with a z-value > 3.09 and a volume of at least 216 mm^3 (8 measured voxels) were considered.*

We also investigated the analogous word order contrast between the conditions with two animate arguments (S_AO vs. OS_A), but the only activations observable in this contrast were found in superior occipital gyrus of the left hemisphere and in the left and right basal ganglia (BG) (see Table 3b).

In contrast to previous findings on word order variations, the average activation for S_IO vs. OS_I in the present experiment is located in the very posterior portion of the superior part of the pars opercularis. Thus, as Figure 2 shows, it not only involves the inferior precentral sulcus, but also the anterior portion of the ventral premotor cortex. In this context the effect of possible interindividual variations was also considered. Thus, we examined the critical activation per subject rendered on that subject's individual anatomy against a probability map of the pars opercularis (Tomaiuolo et al., 1999) to ensure that the activation maximum for each single subject was indeed located within this region. This analysis revealed that 17 participants showed the activation peak for the critical comparison in the pars opercularis proper (mean talairach coordinates x = 51,8, y = 13,8, z = 17,2), while in 3 participants the activation maximum was found in the pars opercularis but at the border of the precentral gyrus (mean talairach coordinates x = 53,3, y = 8,3, z = 27) and 1 participant showed the activation peak in the pars opercularis at the border of the deep frontal operculum (x = -35, y = 9, z = 21). Thus, on account of the fact that the activation lies in the pars opercularis proper for the vast majority of participants, we will continue to refer to the S_IO vs. OS_I contrast as yielding increased neural activity in the pars opercularis.

To summarize, our results provide consistent evidence that pars opercularis is sensitive to animacy differences in word order variation. Furthermore, the animacy contrast within this region (higher activation for S_IO vs. OS_I) was not accompanied by an activation difference between the two conditions with only animate arguments (S_AO/ OS_A). Thus, the activation difference must be attributed to the *animacy principle* rather than to the *subject-before-object principle* or the *thematic hierarchy principle*.[4]

[4] Interestingly we found one additional side-effect. A comparison of the two conditions with only animate arguments (S_AO/OS_A) with those conditions with one inanimate argument (S_IO/OS_I) showed an activation increase in the left posterior superior temporal sulcus for the conditions containing only animate arguments (mean talairach coordinates x = -47, y = -48, z = 21). This finding might be interpreted in terms of an engagement of this cortical region in the processing of agency (Frith & Frith, 1999) and appears compatible with previous findings revealing an interaction of syntactic and semantic information in the left posterior superior temporal sulcus (Friederici et al., 2003; Bornkessel et al., 2005; Scott & Johnsrude, 2003).

6.4 Discussion

In the current experiment, we investigated the impact of animacy, a non-syntactic feature, on the linear ordering of sentential arguments. Sentences with an initial inanimate subject (S_IO) showed increased activation in the superior portion of the pars opercularis of the left IFG in comparison to sentences with an initial animate object (OS_I). A control comparison using the identical sentence structures with only animate arguments did not show significant differences in the pars opercularis.

Firstly, these results replicate the finding reported in Bornkessel et al. (2005). These authors argued that the activation pattern of the pars opercularis reflects the interaction between the *subject-before-object principle* and the *thematic hierarchy principle*, because sentence types violating either one or the other of these principles did not yield activation differences within this region. This observation is confirmed by the interaction between animacy and word order observed in the present study: whereas our control comparison between sentences involving two animate arguments (S_AO/ OS_A) did not lead to a significant activation difference within the pars opercularis, the conditions involving an animacy variation did differ from one another in this region. On account of this interaction, the activation increase for the order inanimate-before-animate (S_IO) in comparison to animate-before-inanimate (OS_I) must be attributed to a violation of the *animacy principle*. Moreover, these data show that it is not the presence of an inanimate subject per se that leads to increased activation within the pars opercularis, but rather the relative ordering between animate and inanimate arguments.

These findings therefore support the linearization hypothesis of pars opercularis function that was first proposed in Bornkessel et al. (2005) and Grewe et al. (2005). This hypothesis postulates that the pars opercularis is sensitive to a range of principles determining linear order in a given language. As these linearization regularities (e.g. animacy) are drawn from a large body of language-comparative research, they constitute a well-constrained set of principles governing word order preferences/rules in a wide range of languages (Comrie, 1989; Croft, 2003). While previous findings showed an influence of purely syntactic linearization principles (subject-before-object; Ben-Shachar et al., 2003; Ben-Shachar et al., 2004; Caplan et al., 2000) or of principles at the interface between the syntax and other linguistic domains (thematic structure:

Bornkessel et al., 2005; discourse saliency/phonological weight: Grewe et al., 2005), the present study is the first to provide evidence for the independent application of a purely semantic principle, namely animacy. Taken together, these findings indicate that the sequential order of arguments within a clause provides a melting pot for linearization parameters stemming from a variety of linguistic domains.[5] This observation additionally serves to highlight how complex a task the language processing system must accomplish in performing the form-to-meaning mapping during efficient real-time communication, since information from these very different domains must be bound together and weighted appropriately in order for interpretation to be successful.[6]

In addition to providing more fine-grained evidence on the nature of the interaction of different linearization principles, the present study adds a further interesting dimension to the linearization hypothesis. Recall that, in contrast to previous studies, the animacy-induced activation observed here was very close to the inferior precentral sulcus, thereby engaging both the posterior portion of the pars opercularis and the anterior portion of the vPMC. On the one hand, this may have been due to a certain amount of interindividual variability: as revealed by our analysis of individual participant data, three participants showed an activation maximum at the border to ventral premotor cortex. A second possibility is that, on account of its primordial nature,

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[5] In fact, the scope of the linearization/sequencing capacity of the pars opercularis proper appears to extend to further domains of language processing. Gelfand and Bookheimer (2003) found an activation increase in Broca's area for the processing of phonemes and hummed notes in a sequence manipulation task compared to a match task. Thus, the observed activation increase in this cortical region might also be interpreted in terms of an engagement in general processes of hierarchical linearizing or sequencing.

[6] Evidence for the impact of animacy in sentence comprehension also becomes apparent in aphasic patients. A study with aphasic speakers of Hindi investigating the relative ranking of three cues to agenthood (word order, noun animacy, and subject-verb agreement) indicates that these patients use animacy as the strongest feature in assigning grammatical roles (Vaid and Pandit, 1991). Interestingly, a strong effect of animacy has also been shown for aphasic speakers of Turkish (MacWinney et al., 1991). Animacy thus plays a stronger role than word order in Turkish and Hindi. Both of these languages are SOV languages and therefore comparable to German in that the noun phrases have to be interpreted before the verb is encountered. Thus animacy is used as a decisive feature in sentence interpretation here whereas SVO languages like English show a greater use of word order (MacWinney et al., 1991).
Several further studies report a sensitivity of Broca's aphasics to animacy. Thus it was shown that the comprehension of inanimate constituent questions in French Broca's aphasics is worse than that of animate ones (Van der Meulen, 2004). For English Broca's patients it has also been found that inanimate constituent questions are more difficult to understand that their animate counterparts (Grodzinsky, 1995; Thompson et al., 1999). These findings thus provide converging support for the fundamental importance of animacy in sentence comprehension and its neurological relevance.

the linearization rule examined here (animate-before-inanimate) may draw not only upon the highly abstract linearization properties represented in the pars opercularis, but also upon more basic sequencing operations supported by the ventral premotor cortex (Schubotz & von Cramon, 2003). Finally, it cannot be ruled out that the individual differences in the localization of the activation maximum may have resulted from differences in the processing strategy employed. Thus, activation of the precentral gyrus has been linked to aspects of motor planning in speech (see Dronkers, 1996; Riecker et al., 2005) and might therefore be indicative of inner speech. However, whether particular properties of individual linearization principles indeed manifest themselves in terms of subtle neuroanatomical distinctions - or strategic processing differences - must be investigated further in future research.

6.5 Conclusions

By manipulating the feature animacy in German ditransitive passive constructions, we were able to show that the pars opercularis of the left IFG is not only sensitive to syntactic linearization principles but also shows enhanced activation when a non-syntactic linearization rule is violated. The present data therefore demonstrate that the pars opercularis engages in a crucial aspect of the form-to-meaning mapping during sentence comprehension by reconstructing the interpretive status of sentential arguments from their linear position in the sentence. In addition to syntactic parameters (e.g. the *subject-before-object principle*), this reconstruction encompasses principles from further linguistic domains such as semantics. In this way, our findings demonstrate that approaches attempting to model sentence-level activation differences within the pars opercularis within a single linguistic domain fail to account for the full range of the data.

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7. Experiment 2:

The Role of the Posterior Superior Temporal Sulcus in the Processing of Unmarked Transitivity

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Is it living or not? The ability to differentiate between animate and inanimate entities is of considerable value in everyday life, since it allows for the dissociation of individuals that may willfully cause an action from objects that cannot. The present fMRI study aimed to shed light on the neural correlates of animacy at a relational-interpretive level, i.e. on the role of animacy in the establishment of relations between entities that are more or less likely to cause an event and differ in their potential to act volitionally. To this end, we investigated the processing of visually presented transitive German sentences (nominative-accusative structures) in which the factors animacy and argument order were manipulated. The relations between the arguments differed in that the animate subject either acted on an inanimate object (a very natural construction in terms of transitivity) or on an animate object (resulting in a sentence deviating from an unmarked transitive structure). Participants performed an acceptability judgment task. Violations of unmarked transitivity yielded a significant activation increase within the posterior left superior temporal sulcus (pSTS), thus suggesting a specific role of this cortical region in the relational use of animacy information. This result indicates that the influence of animacy as a relational feature differs from the impact of this parameter on the word level and is in line with other neuroimaging studies showing an engagement of the pSTS when a matching between syntax and semantics is required. A comparison between object- and subject-initial conditions further revealed a robust effect of argument order in the pars opercularis of the left inferior frontal gyrus (a subregion of Broca's area), thereby replicating previous findings demonstrating a sensitivity of this region to fine-grained language-specific linearization rules.

Key words: language comprehension, animacy, posterior superior temporal sulcus, linearization principles, argument order, pars opercularis, transitivity

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7.1 Introduction

Animacy is undoubtedly one of the most important concepts in higher cognition: animate entities are much more likely to cause an event than inanimate entities, and only animates can be assumed to willfully engage in such an act of causation. Identification of the feature animacy therefore forms a crucial part of action perception and planning and thereby constitutes an essential ability in everyday life.

In addition, animacy has long been considered a decisive feature in language. For example, animacy distinctions have been observed in relation to category-specific deficits in aphasia (e.g. Caramazza and Shelton, 1998). Moreover, animacy is an important explanatory concept in cross-linguistic research as it determines word order, morphological marking and sentence interpretation in a wide range of languages. Many of these phenomena can be accounted for with reference to the following three-tiered hierarchy: *human* > *animal* > *inanimate*. While this hierarchy is assumed to be universal, it may be reflected in different linguistic properties depending on the language under consideration. In close correspondence to the domain-general importance of animacy described above, linguists have therefore assumed that "animacy is a universal conceptual category that exists independently of its realization in any particular language" (Comrie, 1989, p. 186).

Interestingly, linguistic research at the sentence level has emphasized the importance of animacy as a *relational* property rather than focusing on the difference between animate and inanimate entities per se.[1] On the one hand, there is a general tendency in the languages of the world for animate arguments (sentence participants) to precede inanimate (or less animate) arguments (Tomlin, 1986). On the other hand, animacy plays a crucial role in the "information flow" from the A[gent] to the P[atient] of a transitive sentence, i.e. a sentence describing an event with two participants. Following Comrie, "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"

[1] Throughout the remainder of the paper, we will therefore use the term "relational" to refer to aspects of processing pertaining to the relation between arguments (sentence participants) rather than to properties of individual arguments. For example, the processing of an inanimate subject is not costly in and of itself. Costs arise, however, when an inanimate subject acts upon an animate object (see Bornkessel and Schlesewsky, 2006).

(Comrie, 1989, p. 128). Sentences deviating from this notion of "unmarked transitivity", for example by describing an event in which an inanimate entity acts upon an animate entity (e.g. *The rock hit Bill on the head.*), show distinct morphosyntactic behavior (e.g. additional morphological marking) in many languages or are even ruled out completely (see Aissen, 2003).[2] Yet even in languages where such sentences are straightforwardly possible (e.g. English or German), they are generally considered more "marked" and, accordingly, have been shown to engender additional processing costs in behavioral experiments. Thus, in a self-paced reading experiment Lamers (2001) investigated subject-initial sentences with an embedded clause followed by a main clause and demonstrated faster reading times for animate-inanimate orders in comparison to inanimate-animate orders. Furthermore, a number of self-paced reading and eyetracking studies on English and Dutch have revealed that the well-known processing disadvantage for object as opposed to subject relative clauses (King & Kutas, 1995; Müller et al. 1997; Gibson, 1998; Gibson, 2000) is attenuated or even neutralized when the object relative clause adheres to unmarked transitivity (i.e. when the head noun and, thereby, the relative clause object is inanimate and the relative clause subject is animate) (Mak et al., 2002; Mak et al. 2006; Traxler, 2005).

In contrast to the large body of theoretical and descriptive research on the relational role of animacy, the neural mechanisms underlying the relational use of this feature during sentence comprehension are substantially less well- examined. In the electrophysiological domain, deviations from unmarked transitivity have been shown to engender an N400 effect (Frisch and Schlesewsky, 2001; see also Weckerly and Kutas, 1999). However, it has not yet been investigated whether the relational impact of animacy in sentence comprehension can also be associated with particular neural regions.

In the neuroimaging literature, investigations of animacy have largely been restricted to the level of words or pictures depicting individual entities (but see below for a discussion of neuroimaging studies that may lead to a perception of animacy via indirect means). In the vast majority of these studies, animate vs. inanimate entities

[2] Note that "unmarked transitivity" in this sense is quite distinct from "unmarked word order", which refers to a word order than can be felicitously uttered in the absence of any constraining context (Siwierska, 1988). Throughout the remainder of this paper, we will therefore always refer to either "unmarked transitivity" or to "unmarked word order", rather than simply referring to "unmarked sentences" in order to avoid confusion.

yielded increased activation in the lateral fusiform gyrus (LFG), particularly in the right hemisphere (Caramazza and Mahon, 2005; Chao et al., 1999a; Chao et al., 1999b; Kanwisher, 1997; Perani et al., 1999). This finding is very robust and independent of task and presentation mode (words vs. pictures). From a broader perspective, it has been interpreted as reflecting differences in the functional neuroanatomy underlying the recognition of "living things" vs. "non-living things" (Thompson-Schill, 2003). Several studies also report activation in the superior temporal sulcus (STS), again particularly in the right hemisphere (Caramazza and Mahon, 2005; Chao et al., 1999a; Chao et al., 1999b; Haxby et al., 1999; Hoffman and Haxby, 2000; Martin and Chao, 2001; Tyler et al., 2003). However, the STS activations were typically restricted to a subset of participants.

At the sentence level, only two fMRI studies have examined the influence of animacy (in unimpaired individuals). Both were primarily concerned with the relation between animacy and word order. Chen, West, Waters, and Caplan (2006) found that the well-known activation increase for object vs. subject relative clauses in Broca's region was only observable for sentences such as *The golfer that the lightning struck survived the incident*, i.e. sentences in which the head noun and object of the relative clause (*golfer*) was animate and the relative clause subject was inanimate. No comparable activation increase was observed in this region for sentences with inanimate head nouns, e.g. *The wood that the man chopped heated the cabin*, thus supporting the behavioral findings on animacy and relative clause processing discussed above (Mak et al., 2002; Mak et al. 2006; Traxler, 2005). Chen and colleagues concluded from their results that the inferior frontal activation does not reflect a general structural property of the sentences under investigation, but is rather crucially influenced by "noun animacy order".

In another recent fMRI study, Grewe, Bornkessel, Zysset, Wiese, von Cramon, and Schlesewsky (2006) were able to show that, beyond simply attenuating the effects of word order variations, differences in the ordering of animate and inanimate arguments can also lead to activation *increases* in sentences with a canonical word order. The experimental results revealed increased activation in the pars opercularis of the left inferior frontal gyrus (IFG) for subject-initial German sentences with an inanimate argument preceding an animate one (e.g. *Gestern wurde der Mantel dem Arzt gezeigt,* lit.: 'yesterday was [the coat]$_{\text{NOM}}$ [the doctor]$_{\text{DAT}}$ shown') in comparison to (dative) object-initial sentences with an animate-inanimate argument order (*Gestern wurde dem Arzt der Mantel gezeigt,* lit.: ‘yesterday was [the doctor]$_{DAT}$ [the coat]$_{NOM}$ shown’).

Taken together, the experiments by Chen et al. (2006) and Grewe et al. (2006) provide evidence that the effects of animacy as a linearization parameter correlate with activation in the left IFG, and particularly the pars opercularis. These results thus support accounts of the role of the pars opercularis in the processing of word order which emphasize the importance of a range of ordering parameters such as grammatical functions, thematic roles, referential status etc. (Bornkessel et al., 2005; Grewe et al., 2005). However, they are less informative with respect to the neural correlates of animacy at the relational-interpretive level, since a reconstruction of the same underlying relation was always required, although from different linear orders.

Nonetheless, the experiment by Grewe and colleagues provides at least an initial piece of evidence as to the functional neuroanatomy of animacy as a relational feature at the sentence level. An additional comparison examining possible activation differences between the conditions with an animacy contrast (see above) and two further conditions without an animacy contrast (i.e. sentences analogous to the examples given above, but with two animate arguments) yielded an activation increase in the posterior portion of the left STS (pSTS) for the conditions with only animate arguments. This finding might therefore be taken as a tentative first indication that the left pSTS supports relational sentence interpretation involving the feature animacy. Notably, this hypothesis is compatible with previous neuroimaging data demonstrating an engagement of the pSTS in the mapping between interpretive and syntactic argument hierarchies (Bornkessel et al., 2005). Moreover, the pSTS has been implicated in the processing of visual cues like moving eyes or hands (Pelphrey et al., 2005; Wright et al., 2003) or during the presentation of visual motion displays like drifting random dots, or point-light walkers (Grezes et al., 2001; Saygin, 2006). It was even shown that the degree of interactivity of the presented objects on the screen influenced the strength of activation in that cortical region (Schultz et al., 2005). Biological motion is often interpreted as an important cue for the detection of agency, a process which requires the identification of animate entities. The pSTS might therefore provide an interface between the processing of non-linguistic agency (Frith and Frith, 1999) and the type of animacy-based, relational processing that is required for successful sentence comprehension.

The present fMRI study aimed to further investigate the hypothesis that the left pSTS crucially engages in the processing of animacy information at the relational sentence level. To this end, we examined the processing of German sentences involving either an animacy contrast (i.e. an animate subject and an inanimate object) or no such contrast (i.e. two animate arguments). In contrast to our previous study, active rather than passive sentences were used and objects bore accusative rather than dative case marking. As the combination of passive sentences and dative case marking results in a special configuration in German, the influence of other factors cannot be fully ruled out. In particular, the sentences used in the study by Grewe et al. (2006) included a subject argument that is interpretively lower-ranking than its object co-argument, i.e. the argument primarily affected by the action being described is the subject rather than the object of the sentence. Precisely this kind of setting, i.e. an inherently marked form-to-meaning mapping, was shown to lead to increased activation in the left pSTS in Bornkessel et al. (2005). From this perspective, the presence of an inanimate subject in the Grewe et al. (2006) study may have attenuated the mapping difficulty, thus leading to less activation in the pSTS. This would, however, call for a fundamentally different interpretation to an increased activation due to a deviation from unmarked transitivity.

In contrast to Grewe et al. (2006), the present study therefore examined sentences with a straightforward mapping between form and meaning in that only active sentences were used and the subject was therefore always the argument responsible for the event being described (the Agent). The crucial animacy manipulation with respect to the object thus did not affect the argument hierarchy and also had no influence on agentivity. Our four critical sentence conditions, which resulted from a 2x2 design crossing the factors animacy (animacy contrast vs. no animacy contrast) and argument order (subject-object vs. object-subject), are shown in Table 1.

Condition	**Example**
SO_I	Wahrscheinlich | hat | der Mann | den Garten | gepflegt. probably has [the man]$_{NOM}$ [the garden]$_{ACC}$ taken care of 'The man problaby took care of the garden.'
O_IS	Wahrscheinlich | hat | den Garten | der Mann | gepflegt. probably has [the garden]$_{ACC}$ [the man]$_{NOM}$ taken care of 'The man probably took care of the garden.'
SO_A	Wahrscheinlich | hat | der Mann | den Direktor | gepflegt. probably has [the man]$_{NOM}$ [the director]$_{ACC}$ taken care of 'The man probably took care of the director.'
O_AS	Wahrscheinlich | hat | den Direktor | der Mann | gepflegt. probably has [the director]$_{ACC}$ [the man]$_{NOM}$ taken care of 'The man probably took care of the director.'

Table 1: *Critical sentence conditions in the present experiment. Stimulus segmentation is indicated by the vertical bars. Abbreviations used: OS = object-before-subject (permuted); SO = subject-before-object (non-permuted); NOM = nominative; ACC = accusative; O_I = inanimate object; O_A = animate object.*

In addition to the animacy contrast described above, the design shown in Table 1 also allows us to investigate the influence of argument order on the neural processing of unmarked transitivity. Thus, it cannot be ruled out that the relational influence of animacy in argument interpretation is crucially modulated by argument order. Initial evidence that this might indeed be the case stems from Bornkessel et al.'s (2005) study, in which properties of the argument hierarchy interacted with word order in the left pSTS.

Our hypotheses are as follows. For the comparison between sentence conditions without an animacy contrast (SO_A/O_AS in Table 1) and sentences with an animacy contrast (SO_I/O_IS), we expect to observe increased activation in the left pSTS in the former on account of the deviation from unmarked transitivity. Furthermore, if the processing of animate vs. inanimate entities per se is also relevant at the sentence level, sentences with two animate arguments as opposed to one should also yield increased bilateral activation in the lateral fusiform gyrus (LFG; as found, for example, by Chao et al., 1999a; Chao et al., 1999b; see the discussion of animacy at the word level, above).

With respect to the argument order manipulation, object-initial sentences should engender increased activation in the pars opercularis of the left IFG (Röder et al., 2002; Grewe et al., 2005; Bornkessel et al., 2005; Friederici et al., 2006). Regarding possible influences of animacy in the pars opercularis, there are two possibilities. First, if the influence of animacy as a linearization parameter is analogous to that observed in Grewe et al. (2006), condition O_IS should show an even higher activation level in the pars opercularis than condition O_AS. We should therefore observe an interaction between animacy and argument order in this region. Alternatively, it may be the case that animacy plays a different role in nominative-accusative structures of the type examined here than in nominative-dative structures of the type examined in Grewe et al. (2006). Thus, only the latter allow for an unmarked object-initial order, i.e. an object-first order that is judged to be just as acceptable as its subject-initial counterpart or even more so. Sentences with an accusative object preceding the subject, by contrast, are always more marked than sentences with a nominative-before-accusative word order (Schlesewsky and Bornkessel, 2004). If the pars opercularis is sensitive to this very fine-grained word order distinction, we do not expect to observe an animacy effect within this region.

7.2 Materials and methods

7.2.1 Participants

19 students (10 females; mean age 25.21; age range 20-30 years) took part in the fMRI study. All participants were monolingual, native speakers of German, had normal or corrected-to-normal vision, and were right-handed as indicated by a German version of the Edinburgh Inventory (Oldfield, 1971). Informed written consent was obtained from all participants prior to the scanning session. Two further participants were excluded from the final data analysis on account of movement artifacts.

7.2.2 Materials

Four types of grammatically correct German active sentences were used in the present study (see Table 1). Only unrelated noun phrase combinations were chosen, in order to avoid differences in lexical-semantic relatedness across conditions. Furthermore, the object nouns (which differed between conditions SO_I/O_IS and SO_A/O_AS) did not differ with respect to word frequency (Mann-Whitney-Test; U-test = 539.5; $p > 0.633$; word frequencies taken from the corpus of the *Projekt Deutscher Wortschatz*; http://wortschatz.uni-leipzig.de). The mean values for word frequency were: animate object nouns (10.62); inanimate object nouns (10.94). All nouns were of masculine gender so that case marking (nominative vs. accusative) was always unambiguous. To balance out the acceptability for the behavioral task (see below) these critical sentences were interspersed with 2 types of grammatically incorrect German active constructions. Each of the conditions contained 34 sentences which where presented visually to every participant. The critical sentences comprised a sentence-initial adverb which was followed by a finite auxiliary, two arguments, and a clause-final participle. A similar form was applied to the ungrammatical fillers, but these constructions contained an incorrectly positioned participle. Altogether the participants read 204 sentences, of which 68 were highly acceptable (the subject-initial sentences), 68 were unacceptable (the ungrammatical fillers) and 68 were of degraded acceptability (the object-initial sentences). To improve statistical evaluation of the data (Miezin et al., 2000), 34 null events (empty trials) were introduced. The total number of trials therefore added up to 238 per participant.

7.2.3 Procedure

The experimental sentences were read via LCD goggles (Visuastim; Magnetic Resonance Technology, Northridge, CA) by all participants. To control for reading strategies, sentences were presented in a segmented manner. Every segment was presented for 400 ms in the centre of the screen with an interstimulus interval (ISI) of 100 ms (segmentation indicated in Table 1). At the beginning of each trial an asterisk occurred for 300 ms (plus 200 ms ISI) while the presentation of the sentences always ended with a 500-ms pause. Finally, a question mark signaled to participants that a behavioral response was required and their task was to judge the acceptability of the preceding sentence. The participants accomplished this judgment task by pressing one of two push-buttons with their right index and middle fingers and were given maximally 2500 ms to respond. The assignment of fingers to acceptable and unacceptable was counterbalanced across participants.

The trials were presented with variable onset delays of 0, 400, 800, 1200, or 1600 ms, thereby leading to an oversampling of the actual image acquisition time of 2000 ms by a factor of five (Miezin et al., 2000). Every trial had a length of 8 s, resulting in a total measurement time of 32 min, which was separated into two functional runs.

Each participant completed a short practice session before entering the scanner.

7.2.4 fMRI data acquisition

Twenty axial slices (19.2 cm FOV, 64 by 64 matrix, 3 mm thickness, 0,6 mm spacing), parallel to the AC-PC plane were collected on a 3T scanner (Medspec 30/100, Bruker, Ettlingen). Therefore a single shot, gradient recalled sequence (TR 2000 ms, TE 30 ms, 90° flip angle) was used. As the main focus of the experiment was on the activation of temporal regions and of the pars opercularis of the IFG, the slice thickness and spacing were chosen to allow for a relatively high spatial resolution for these regions of interest. For this reason, it was not possible to cover the whole head and no signal was acquired for superior parts of the frontal and parietal lobes as well as for inferior parts of the cerebellum. The exact slice coverage depended on individual brain size.

Two functional runs of 484 time points were collected (including two “dummy” trials at the beginning of each run, which did not enter the data analysis), with each time point sampling over the 20 slices. Prior to the functional runs, 20 anatomical T1-weighted MDEFT (Ugurbil et al., 1993; Norris, 2000) images (data matrix 256x256, TR 1300 ms, TE 10ms) and 20 T1-weighted EPI images with the same geometrical parameters as the functional data were acquired.

7.2.5 fMRI data analysis

The analysis of the fMRI data was conducted by using the LIPSIA software package (Lohmann et al., 2001). This software contains tools for preprocessing, registration, statistical evaluation and presentation of fMRI data.

In a first step, the functional data were corrected for motion using a matching metric based on linear correlation. A cubic-spline-interpolation based on the Nyquist-Shannon-Theorem was applied to correct for the temporal offset between the slices acquired in one scan. The baseline correction of the signal was done by using a temporal highpass filter with a cutoff frequency of 1/112 Hz and a spatial Gaussian filter with 5.65 mm full width half-maximum (FWHM) was applied.

Furthermore, a rigid linear registration with six degrees of freedom (3 rotational, 3 translational) was performed to align the functional data slices onto a 3D stereotactic coordinate reference system. To achieve an optimal match between these slices and the individual 3D reference data set the rotational and translational parameters were acquired on the basis of the MDEFT and EPI-T1 slices. This 3D reference data set was acquired for each subject during a previous scanning session. The MDEFT volume data set with 160 slices and 1mm slice thickness was standardized to the Talairach stereotactic space (Talairach and Tournoux, 1988). The same rotational and translational parameters were normalized, i.e., transformed to a standard size via linear scaling. The resulting transformation parameters were then applied to the functional slices via trilinear interpolation, so that the resulting functional slices were aligned with the stereotactic coordinate system. A subsequent processing step that performs an additional non-linear normalization (Thirion, 1998) yielded an improvement of the linear normalization process.

The statistical evaluation was based on a least-squares estimation using the general linear model for serially autocorrelated observations (see also Friston et al., 1995; Worsley and Friston, 1995; Aguirre et al., 1997; Zarahn et al., 1997). The design matrix was generated with a box-car function convolved with the hemodynamic response function. The model equation, including the observation data, the design matrix as well as the error term, was convolved with a Gaussian kernel of dispersion of *4 sec. FWHM* to deal with the temporal autocorrelation (Worsley and Friston, 1995). In a next step, contrast maps were generated for each subject. The ungrammatical filler sentences were modeled as covariates of no interest such that only the four critical conditions entered the contrasts of interest. As the individual functional datasets were all aligned to the same stereotactic reference space, a group analysis was performed. The single-participant contrast-images were entered into a second-level random effects analysis for each of the contrasts. The group analysis consisted of a one-sample t-test across the contrast images of all subjects that indicated whether observed differences between conditions were significantly distinct from zero (Holmes and Friston, 1998). Finally, a transformation of t values into Z scores was computed. Only regions with a Z score greater than 3.09 ($p < 0.001$ uncorrected) and with a volume greater than 270 mm^3 (10 measured voxels) were considered (Braver and Bongiolatti, 2002; Forman et al., 1995). In order to ensure that this cluster size would be adequate to protect against false positives, we performed a MonteCarlo simulation (http://www.afni.nimh.nih.gov/afni/doc/manual/AlphaSim) to determine the non-arbitrary cluster-size. This simulation revealed that a volume of 5 voxels (135 mm^3) corresponded to an alpha error probability level of $p < 0.01$, thus indicating that the combined Z-score and volume-based threshold applied here were indeed appropriate.

7.3 Results

7.3.1 Behavioral data

For the analysis of the behavioral data, repeated-measures analyses of variance (ANOVAs) were computed using the factors animacy (ANI: I vs. A) and word order (ORDER: SO vs. OS).

The mean acceptability rates in the behavioral task were: SO_I (98%; sd = 0,22); O_IS (30%, sd = 0,26); SO_A (97%, sd = 0,33); O_AS (32%, sd = 0,31). Thus, there was a main effect for the factor ORDER in the global analysis (ORDER (F (3,54) = 108.75; p < .0001), while neither a main effect for ANI (ANI (F<1)) nor an interaction between the two factors could be found (ANI BY ORDER (F (3,54) = 1.58 ; p = .23)).

The reaction times showed the following mean values per condition: SO_I (478 ms, sd = 98); O_IS (754 ms, sd = 260); SO_A (497 ms, sd = 97); O_AS (798 ms, sd = 310). While the global analysis again revealed a significant main effect for the factor ORDER (F (3,54) = 22.34 p > .0001), the factor ANI showed no main effect (ANI (F (3,54) = 3.35; p = .08), and the interaction between both factors was not significant (ANI BY ORDER: (F<1).

In this way, the acceptability ratings as well as the reaction time differences confirm the predictions for the experimental manipulation.

7.3.2 fMRI data

On account of our hypothesis concerning the neural correlates of animacy as a relational feature, we first computed a direct contrast between the conditions involving only animate arguments and those conditions with one animate and one inanimate argument (O_AS/SO_A vs. O_IS/SO_I). As is apparent from Figure 1a and Table 2, the results of this contrast reveal a significant activation increase in the left posterior STS for sentences with two animate arguments compared to conditions including an animacy contrast. Furthermore, this contrast yielded activation maxima in left posterior cingulate cortex (PCC) and left middle temporal gyrus (MTG) (see Figure 1b/c).

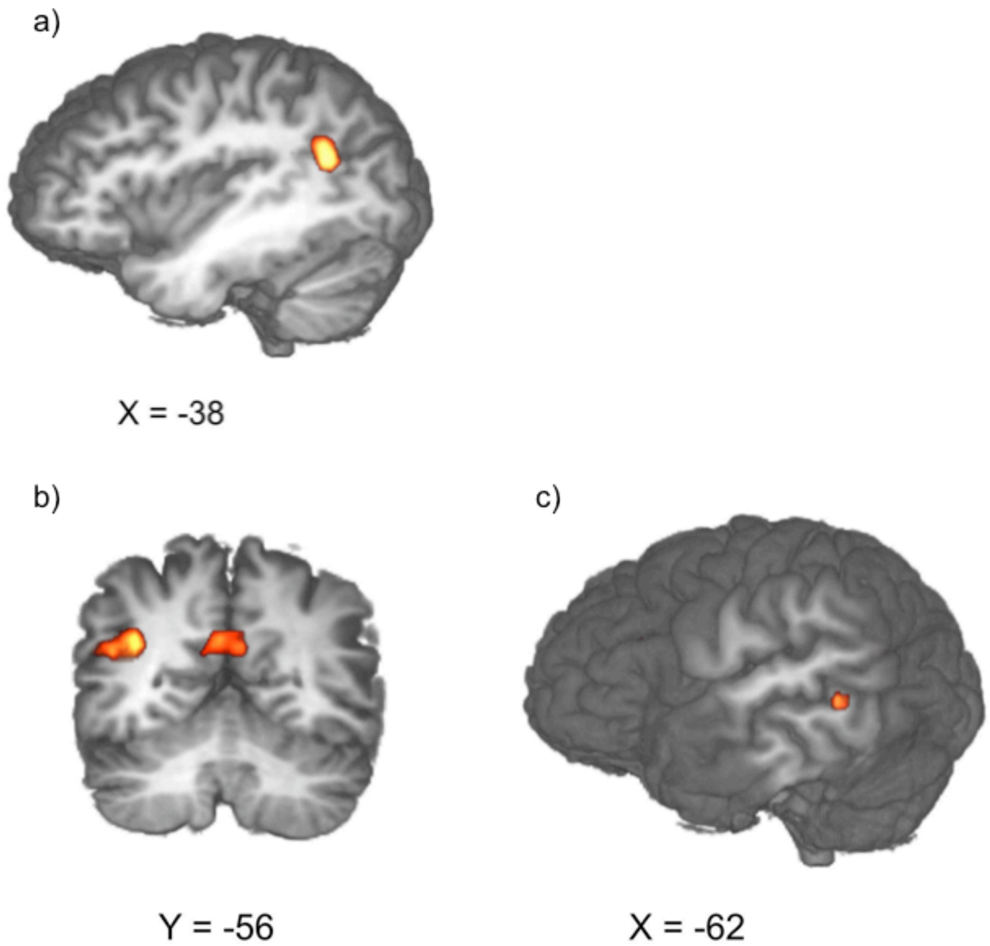

Figure 1: *Average activations for the contrast between sentences with two animate arguments (SO_A/O_AS) and sentences with one animate argument and one inanimate argument (SO_I/O_IS) with a z-value > 3.09: a) sagittal: left pSTS (-38 -59 27); b) coronal: left PCC (-5 -56 27) & pSTS; c) sagittal: left MTG (-62 -47 3). Colours used: SO_A/O_AS = red-yellow.*

Region	Talairach coordinates	Max. z-value	Volume (mm^3)
L. posterior superior temporal sulcus (39)	-38 -59 27	4.85	1566
L. posterior cingulate cortex (31)	-5 -56 27	3.89	1566
L. middle temporal gyrus (22)	-62 -47 3	3.99	270

Table 2: *Talairach coordinates, maximal z-values and volumes of the activated region for the local maxima in the contrast between sentences with two animate arguments (SO_A/O_AS) and sentences with one animate argument and one inanimate argument (SO_I/O_IS). Only activations with a z-value > 3.09 and a volume of at least 270 mm^3 (10 measured voxels) were considered.*

In a second step, we extracted the time course of the underlying blood oxygenation level-dependent (BOLD) signal for the regions shown in Table 2. The local maxima within these regions were defined as voxels with the highest z-value exceeding 3.09 ($p < 0.001$, uncorrected) and a volume of at least 270 mm^3 (10 measured voxels). For each condition and participant, the percent signal change for the voxel with the highest z-value and the 26 adjacent voxels (relative to the mean signal intensity over all time points per voxel) was extracted for each of these regions. Subsequently, the time course of the null events was subtracted from the averaged single-event time courses for the critical sentence conditions for each participant (Burock et al., 1998). The results of this time course analysis are shown in Figure 2, which depicts the mean percent signal change in a time window from -2 to +2 s relative to the maximal signal change per participant and condition. As in our previous studies on related issues (Bornkessel et al., 2005; Grewe et al., 2005; Grewe et al., 2006), the time courses were subjected to a repeated measures analysis of variance (ANOVA) involving the factors animacy (ANI, I vs. A) and argument order (ORDER; OS vs. SO). The results of this analysis demonstrate a main effect of ANI in the pSTS (F (1,18) = 38.08, $p < .0001$) but no main effect of ORDER (F (1,18) = 2.40, $p = .14$) and no interaction of ANI x ORDER ($F<1$) in this cortical region. The left PCC shows a main effect for ANI (F (1,18) = 5.03, $p = .04$) but no main effect of ORDER ($F<1$) and no interaction ($F<1$). A main effect of ANI (F (1,18) = 15.86, $p < .0009$) can also be observed in the left MTG but no main effect of ORDER (F (1,18) = 3.19, p = .09) and no interaction (F<1) are found in this region.

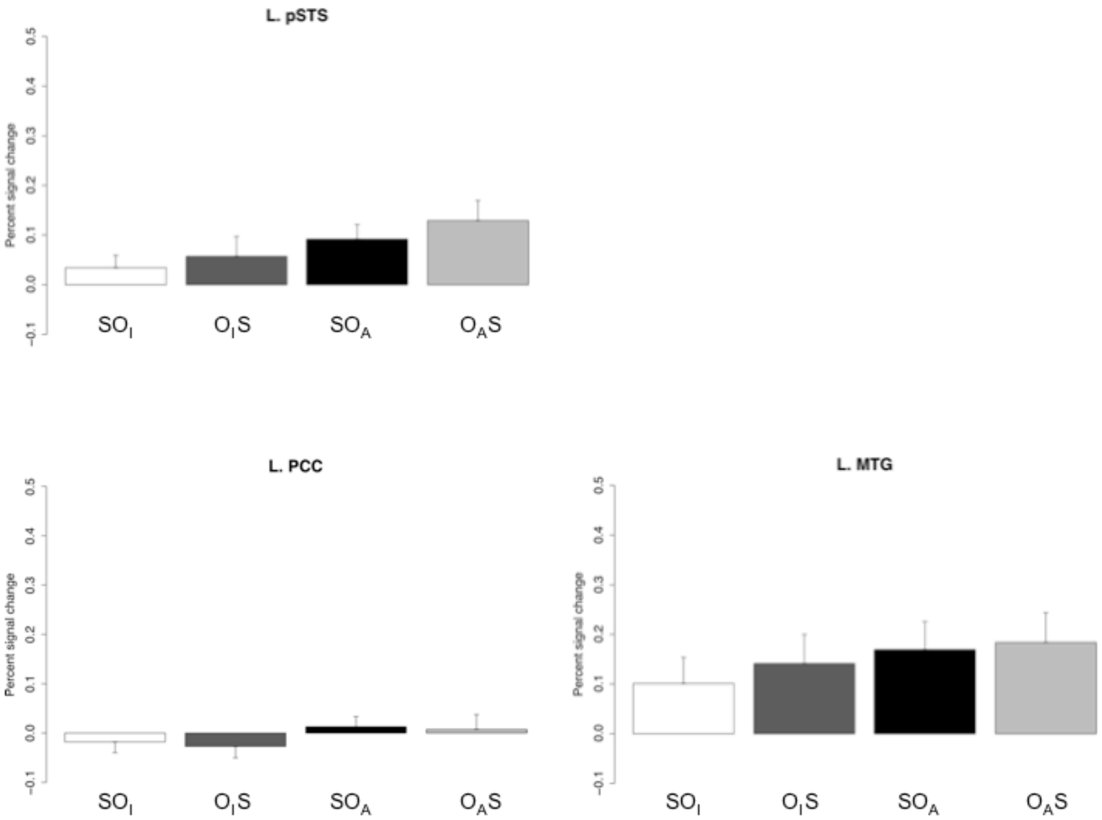

Figure 2: *Average percent signal change (-2 to +2 s relative to the point of maximal signal change) for regions showing a significant effect of ANI for the conditions involving sentences with two animate arguments (SO_A/O_AS). Error bars indicate the standard error of the mean.*

In order to examine the effect of word order, we further computed a contrast between permuted and non-permuted conditions (O_IS/O_AS vs. SO_I/SO_A). Figure 3 and Table 3 show the results of this contrast, namely increased activation for object- vs. subject-initial sentences in the pars opercularis of the left IFG and increased activation for subject- vs. object-initial sentences in the left superior occipital gyrus (OG) and right insulate gyrus (IG).

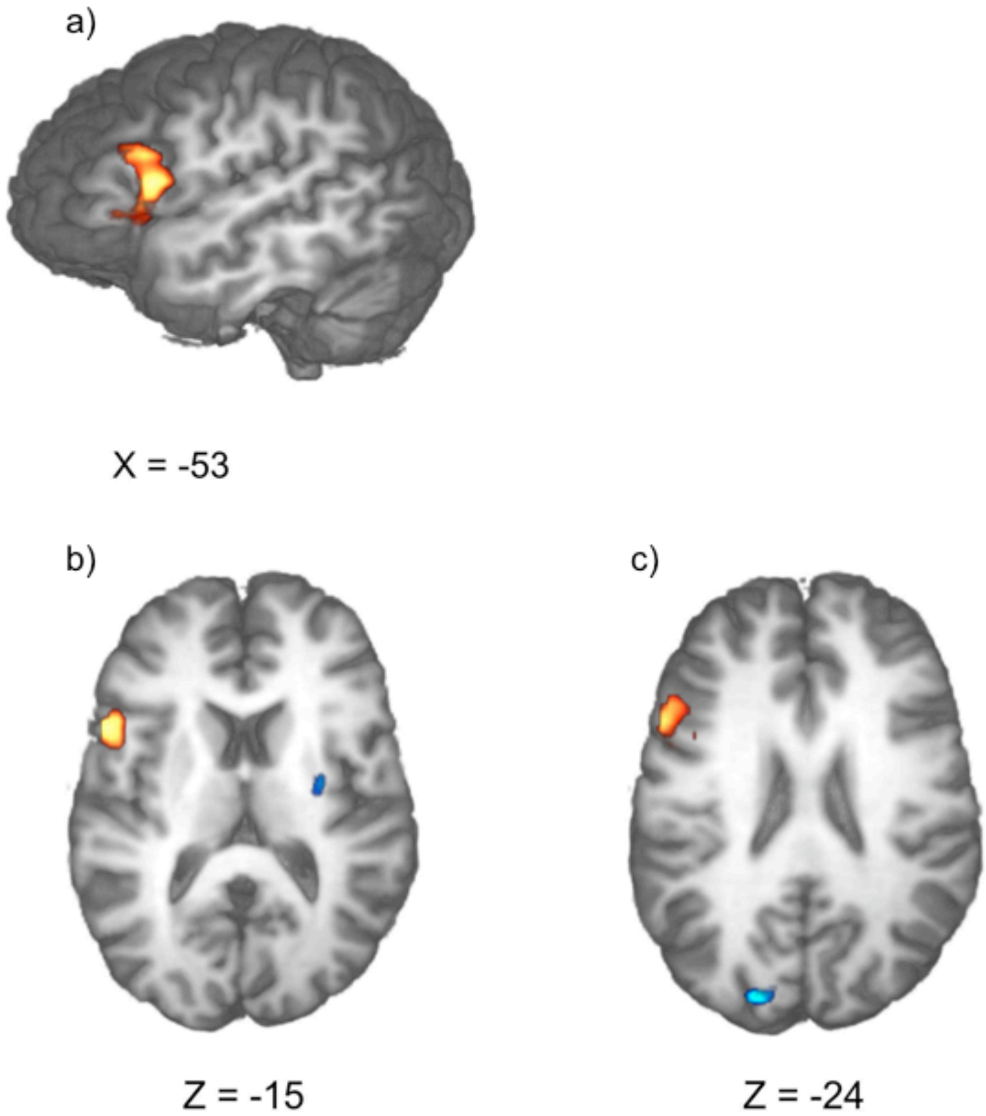

Figure 3: *Average activations for the contrast between sentences with two object-initial conditions (O_IS/O_AS) and their subject-initial counterparts (SO_I/SO_A) with a z-value > 3.09: a) sagittal: left PO (-53 10 15); b) coronal: right IG (28 -8 15) and left PO; c) sagittal: left superior OG (-20 -86 24) and left PO. Colours used: O_IS/O_AS = red-yellow; SO_I/SO_A = blue.*

Region	**Talairach coordinates**	**Max. z-value**	**Volume (mm³)**
L. inferior frontal gyrus (IFG), pars opercularis (44)	-53 10 15	4.40	3780
L. superior occipital gyrus (19)	-20 -86 24	-3.89	486
R. insulate gyrus	28 -8 15	-3.57	297

Table 3: *Talairach coordinates, maximal z-values and volumes of the activated region for the local maxima in the contrast between permuted and non-permuted sentences (O_IS/O_AS vs. SO_I/SO_A). Only activations with a z-value > 3.09 and a volume of at least 270 mm^3 (10 measured voxels) were considered.*

Time course analyses yielded a main effect of ORDER (F (1,18) = 28.29, p < .0001) in the pars opercularis of the left IFG, but no main effect of ANI (F (1,18) = 1.07, p = .31) and no interaction (F<1). A main effect of ORDER (F (1,18) = 7.66, p = .01) was also demonstrated in the left superior OG while, here too, ANI showed no main effect (F<1) and no interaction (F<1) was found. The results of this analysis further indicate a main effect of ORDER (F (1,18) = 8.12, p = .01) in the right IG while no main effect of ANI (F (1,18) = 1.05, p = .32) and no interaction (F<1) were shown (see Figure 4).

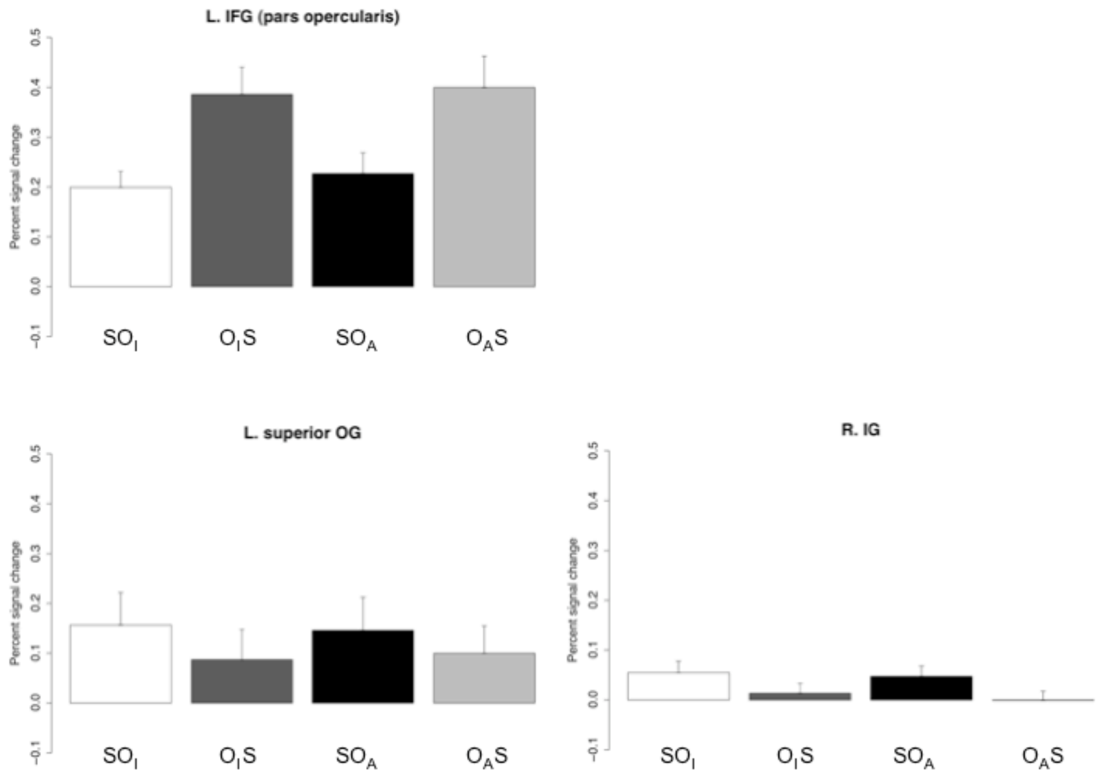

Figure 4: *Average percent signal change (-2 to +2 s relative to the point of maximal signal change) for regions showing a significant effect of ORDER for conditions involving object-initial sentences (O_IS/O_AS) and for conditions involving subject-initial sentences (SO_I/SO_A). Error bars indicate the standard error of the mean.*

Finally, in order to investigate the hypothesis that the pars opercularis might show an interaction between word order and animacy, we additionally computed an interaction contrast $((O_IS\text{-}SO_A)\text{-}(SO_I\text{-}O_AS))$. This contrast yielded no significant activation in the pars opercularis, even when the threshold was lowered to $z > 2.33$ ($p < 0.01$, uncorrected). Rather, at our original threshold ($z > 3.09$) no reliable activation maximum was observed. To completely rule out such an interaction in the pars opercularis, we additionally computed a region-of-interest (ROI) analysis, in which we determined the activation maximum within the pars opercularis for all four critical conditions in contrast to the empty trials and computed time course analyses for this voxel (see Grewe et al., 2006). As the examination of one of our critical hypotheses crucially depended upon the presence or absence of an interaction between word order and animacy in the pars opercularis in the present study, this ROI analysis was performed in order to ensure maximal comparability with the previous experiment in which such an interaction was found. However, the ROI analysis also did not yield a significant interaction, thus confirming the results of the former analysis.

7.4 Discussion

The present study showed that sentences deviating from unmarked transitivity by including an animate object (O_AS/SO_A) showed increased activation in the left pSTS in comparison to unmarked transitive sentences (i.e. sentences with an animate subject and an inanimate object; O_IS/SO_I). This contrast additionally yielded activations in the left MTG and the left PCC which we will not discuss further with respect to the question under consideration. Furthermore, we observed a word order-related activation increase in the pars opercularis of the left IFG (object- vs. subject-initial sentences), but no effects of or interactions with animacy in this region. Besides the pars opercularis activation for object-initial sentences (O_IS/O_AS) this comparison revealed two activations for subject-initial sentences (SO_I/SO_A) in the left superior OG and the right IG.

7.4.1 Posterior superior temporal sulcus

The present findings confirm the hypothesis that the left pSTS engages in the processing of relational animacy information at the sentence level ("unmarked transitivity"). While a previous first indication of such a functional correlation (Grewe et al., 2006) was potentially confounded with the use of an inanimate subject that was also the lower-ranking of two participants (see introduction), the current study avoided this problem by manipulating the animacy of the object. It therefore supports the assumption that activation in the left pSTS correlates with the ease or difficulty of establishing a relation between the two participants of a transitive event. When this relation deviates from unmarked transitivity (i.e. from an A[gent] that outranks the P[atient] with respect to animacy), additional effort is required in order to build up a correct semantic interpretation and/or mental model of the event being described. The pSTS activation observed here thus correlates with the generalization drawn from descriptive studies on the linguistic expression of transitive relations and how this varies across languages.

Importantly, this relational use of animacy at the sentence level is associated with distinct neural correlates from those associated with animacy as a feature of words and objects. Thus, the animacy manipulation in the present experiment did not yield activation in any of the regions typically associated the processing of animate vs. inanimate entities at the word and object level, such as the LFG or the right STS (see Caramazza and Mahon, 2005, for an overview). While activation in the left STS was reported for individual participants in a small number of these studies, a correlation between the left STS and animacy at the word/object level was never reported as reaching significance in a random effects group analysis, as was the case for animacy at the sentence level in this and our previous experiment (Grewe et al., 2006). This observation therefore indicates that the processing of animacy at a relational-interpretive level ("Who is acting on whom/what") indeed adds a distinct functional neuroanatomical component to the network responsible for the processing of animacy. The absence of significant activation in the regions usually responsive to contrasts between individual animate and inanimate entities (at the word or picture level) suggests that the relational use of animacy information may override the perception of animacy as a feature of individual entities. Converging support for this assumption stems from several electrophysiological findings, which suggest that ERP effects for animate and inanimate participants in a sentence context are more strongly determined by relational aspects between the participants than by individual participant features (for an overview and a theoretical psycholinguistic motivation, see Bornkessel and Schlesewsky, 2006).[3]

The relational-linguistic function of the left pSTS assumed here further serves to complement the more general cognitive perspective on this cortical region. In particular, the pSTS has been implicated in the processing of biological motion. Here, the movements of objects as well as their contingency and the degree of interactivity between them are considered important cues for inducing the percept of animacy. In this respect, the interaction between visually presented objects (e.g. one point-light dot

[3] As mentioned in the introduction, deviations from unmarked transitivity have been linked to N400 effects in the electrophysiological domain. Nonetheless, we would be cautious in using this correlation between the pSTS activation in the present study and this ERP component to argue for the pSTS as a potential source of the N400. On the one hand, N400 effects have been associated with an extended neural network comprising multiple sources (Maess et al. 2006) so that a unique link between this component and one particular neural region appears problematic. On the other hand, the correlation between ERP sources and fMRI activation is also relatively complex as shown, for example, by a direct comparison of intracranial ERPs and fMRI (Brazdil et al. 2005).

crashing into another, which then turns into the expected direction) appears to be interpreted as an event involving multiple participants, one of which is perceived as more agentive and, hence, as higher in animacy. Finally, an involvement of the pSTS in the processing of animacy at the sentence-level is highly compatible with the heteromodal and polysensory role of this region in general information processing. Experiments with both humans (e.g. Wright et al., 2003; Spitsyna et al., 2006) and non-human primates (Nelissen et al., 2006) suggest that the pSTS is involved in the processing of a wide range of different information types. With respect to the processing of animacy, this suggests that the pSTS may play a crucial role in binding together various information sources, which, when taken together, give rise to the abstract, relational concept of “animacy”.

The present results therefore underscore the sensitivity of the pSTS to a general relational concept of animacy, which forms the basis for different cognitive processes. Note however, that this should not be taken to imply that the pSTS exclusively engages in animacy-related processes. Such an interpretation would be difficult to reconcile with the many different phenomena correlating with activation in this area.

7.4.2 Inferior frontal gyrus, pars opercularis

As predicted, the word order manipulation (object-before-subject vs. subject-before-object) yielded a robust activation difference in the pars opercularis of the left IFG. This finding replicates a number of previous studies (Röder et al., 2002; Grewe et al., 2005; Bornkessel et al., 2005; Friederici et al., 2006). Note that, while the present results do not allow us to rule out possible influences of factors such as sentence acceptability and working memory in engendering this activation, previous findings have provided strong converging support for the claim that the sensitivity of the left pars opercularis to word order parameters in German cannot be reduced to these factors (e.g. Bornkessel et al., 2005; Grewe et al., 2005; Grewe et al., 2006). For example, Grewe et al. (2005) clearly dissociated effects of linearization parameters in the pars opercularis from acceptability by showing that linearization, rather than acceptability, accounted for the pattern of activation engendered by sentence conditions in which the violation of linearization parameters did not directly correlate with drops in acceptability. Furthermore, Bornkessel et al. (2005) used a comprehension task in an experiment contrasting sentences with different word orders – thus ensuring that participants understood the critical object-initial sentences – and found very similar word order-related activations within the pars opercularis to those observed here (see also Friederici et al., 2006). This latter finding supports the behavioral observation that the acceptability drop associated with the type of object-initial sentences examined here is not accompanied by a concomitant drop in comprehension accuracy (see Schlesewsky and Bornkessel, 2003, for an example of a study in which object-initial sentences engendered a significant drop in acceptability in comparison to their subject-initial counterparts, while the two sentence types did not differ significantly in a comprehension task). In addition, a word order-related activation increase within the pars opercularis can be observed for sentences involving the violation of a linearization parameter even when the critical sentences do not differ with respect to acceptability (see Grewe et al., 2006; Bornkessel et al., submitted). Finally, both Grewe et al. (2005) and Bornkessel et al. (2005) argue in detail that the results of their respective studies cannot be derived by an account appealing solely to differences in working memory load. Thus, within the context of these previous findings on word order variations, an interpretation of the present activation pattern in terms of linearization parameters indeed appears justified.

In contrast to Grewe et al. (2006), the present experiment did not reveal an interaction between word order and animacy in this region. As outlined in the introduction, this difference between the two studies can be plausibly accounted for in terms of the different sentence constructions used in each case. While the structures used in our previous study allowed for an unmarked object-initial word order, the sentences in the present study did not. This distinction and its consequences for the relation between animacy and word order information provides strong converging evidence for the linearization hypothesis of pars opercularis function in sentence processing (Bornkessel et al., 2005; Grewe et al., 2005; Bornkessel et al., submitted). According to this hypothesis, the activation level of the pars opercularis reflects the influence of a variety of linearization parameters stemming from different linguistic domains (e.g. subject-before-object, Actor-before-Undergoer, animate-before-inanimate). While, in a nominative-dative structure (as used in Grewe et al., 2006), the animacy of the arguments determines their linear ordering, animacy does not affect the relative positioning of nominative and accusative arguments (Schlesewsky and Bornkessel, 2004). Thus, while animacy constitutes a linearization parameter in the first scenario, it does not in the second. Strikingly, this theoretically predicted pattern is directly reflected in the activation pattern of the pars opercularis across the two studies.

7.5 Conclusions

The present study showed that the processing of animacy-based relational information at the sentence level correlates with activation in the left pSTS. Deviations from an unmarked relation (i.e. an animate participant acting upon an inanimate participant) lead to increased activation in this region, thus suggesting that the pSTS may provide an interface between animacy- and agentivity-related processes at the linguistic and at more general cognitive levels. Furthermore, we observed a word order-related activation in the pars opercularis of the left IFG that was independent of animacy. This latter finding attests to the sensitivity of the pars opercularis to fine-grained linguistic linearization parameters.

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8. Experiment 3:

The Emergence of the Unmarked: A New Perspective on the Language-specific Function of Broca's Area

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A number of neuroimaging studies have implicated an involvement of Broca's area – and particularly of the pars opercularis of the left inferior frontal gyrus (IFG) – in the processing of complex (permuted) sentences. However, functional interpretations of this region's role range from very general (e.g. in terms of working memory) to highly specific (e.g. as supporting particular types of syntactic operations). A dissociation of these competing accounts is often impossible because, in the vast majority of cases, the language internal complexity of permuted sentence structures is invariably accompanied by increasing costs of a more general cognitive nature (e.g. working memory, task difficulty, acceptability). In the present study, we used functional magnetic resonance imaging to explore the precise nature of the pars opercularis activation in the processing of permuted sentences by examining the permutation of pronouns in German. While clearly involving a permutation operation, sentences with an initial object pronoun behave like simple, subject-initial sentences (e.g. in terms of acceptability) because of a rule stating that pronouns should generally precede non-pronominal arguments. The results of the experiment show that, in contrast to non-pronominal permutations, sentences with a permuted pronoun do not engender enhanced pars opercularis activation. Our findings therefore speak against both language-related working memory and transformation based accounts of this region's role in sentence comprehension. Rather, we argue that the pars opercularis of the left IFG supports the language-specific linearization of hierarchical linguistic dependencies.

Key words: language comprehension, word order, inferior frontal gyrus, pars opercularis, linearization, hierarchization.

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8.1 Introduction

The most fundamental challenge posed by human language arguably lies in determining whether linguistic regularities are somehow "special" or whether they can be derived from the properties of other, independently warranted systems. Whereas a number of researchers have, for example, associated linguistic knowledge with constraints on action and perception (cf., Rizzolatti & Luppino, 2001) or statistical distributions of language use (Jurafsky, 1996), others have defended the claim that language *cannot* be fully accounted for in terms of more general cognitive abilities (e.g., Hauser et al., 2002; Pinker & Jackendoff, in press). Within the field of cognitive neuroscience, the debate on the nature of language has focused extensively on the role of "Broca's area", i.e. the pars opercularis and triangularis of the left inferior frontal gyrus (IFG). On the one hand, this cortical region has been selectively associated with properties deemed to be particular to language (e.g. transformations, Grodzinsky, 2000; or recursion, Friederici, 2004). On the other, however, it has also been found to be involved in the processing of non-linguistic information (such as music, Koelsch et al., 2002; sequencing, Schubotz & von Cramon, 2002b; Schubotz & von Cramon, 2002a; and action recognition, Hamzei et al., 2003).

The linguistic manipulations employed to ascertain whether Broca's region is selectively sensitive to language-specific properties typically vary sentence complexity. Complex sentences have been argued to instantiate properties of language that cannot be straightforwardly associated with analogues in other domains such as action and perception. For example, complexity may be increased by the permutation of sentence constituents, as in the sentence *Snails, I could never imagine eating*. Here, the object *snails* appears before the subject, rather than after the verb, as is typical in English. Indeed, it has been argued that Broca's area responds selectively to such permutations (or "transformations", Grodzinsky, 2000; Ben-Shachar et al., 2003; Ben-Shachar et al., 2004). However, the inherent difficulty in using complex sentences to argue for a language-specific function of Broca's area lies in the fact that – by their very nature – these sentences occur less frequently (e.g., Kempen & Harbusch, 2004a, 2004b), are judged to be less acceptable (e.g., Bader & Meng, 1999; Gibson, 1998) and give rise to increased processing costs in behavioral psycholinguistic paradigms such as self-paced reading (King & Just, 1991; Gibson, 1998). In this way, there are typically inherent differences between complex and simple sentences that cannot be fully reduced to the linguistic manipulation *per se*.

Indeed, a number of researchers have argued that the increased processing cost for complex (permuted) sentences is grounded in the higher working memory demands engendered by these structures (Caplan et al., 2000; Müller et al., 2003; Kaan & Swaab, 2002; Fiebach et al., 2005). From this perspective, the enhanced inferior frontal (Broca's area) activation for permuted (object-initial) sentences is thought to result from the fact that "patient-before-agent sentences impose a larger burden on working memory, because the first noun phrase (corresponding to the eventual patient) cannot be syntactically and thematically integrated until the verb is encountered, and must be retained in working memory until that point" (Kaan & Swaab, 2002, p. 351). While the specific type of working memory thought to be involved in this process is not always clearly defined, the two most explicit claims on the relationship between Broca's region, permuted sentences and working memory (Caplan et al., 2000; Fiebach et al., 2004) both assume a crucial involvement of *syntactic* working memory. This type of approach thus accounts for the activation of Broca's area in the processing of complex sentences by appealing to an interaction between language-internal properties and more general cognitive constraints.

In summary, previous results regarding the role of Broca's region during sentence comprehension have been interpreted both in terms of language-inherent properties such as transformations or recursion (Norris, 2000; Friederici, 2004) and as a result of more general capacity restrictions. However, a dissociation of these competing accounts is often impossible, because, in the vast majority of cases, the language-internal complexity of permuted sentence structures is invariably accompanied by increasing costs of a more general cognitive nature (e.g. working memory, task difficulty, acceptability).

In the present study, we capitalize upon the particular properties of German to tease apart some of these competing factors. In contrast to English, for which deviations from a subject-before-object order are invariably associated with increased processing costs that are independent of the particular experimental method chosen, German permits “unmarked” permuted orders under particular circumstances. This is illustrated by the sentences in (1).[1]

1) a. Dann hat dem Gärtner der Lehrer den Spaten gegeben.
then has [the gardener]$_{IOBJ}$ [the teacher]$_{SUBJ}$ [the spade]$_{DOBJ}$ given
‘Then the teacher gave the spade to the gardener.’

b. Dann hat ihm der Lehrer den Spaten gegeben.
then has him$_{IOBJ}$ [the teacher]$_{SUBJ}$ [the spade]$_{DOBJ}$ given
‘Then the teacher gave him the spade.’

In both (1a) and (1b), the indirect object precedes the subject. In this way, the linear order of the sentential arguments no longer corresponds to the hierarchy of participant roles specified in the lexical entry of the verb (in this case: Agent (the teacher) > Benefactive/Recipient (the gardener/him) > Patient/Theme (the spade)). Both sentences are therefore permuted in the sense that they do not allow a direct mapping from the surface ordering of the arguments to the conceptual structure of the verb frame (e.g., Baker, 1988; Perlmutter & Postal, 1984; Wunderlich, 1997). In this way, the two sentence types both involve a transformation and induce increased working memory costs in the sense that the indirect object must be maintained in memory until it can be integrated. Moreover, the frequency disadvantage for object-initial structures in comparison to their subject-initial counterparts is comparable for (1a) and (1b) (Schlesewsky et al., 2003).

Despite these commonalities, however, it is undisputed from both a theoretical and an empirical perspective that (1a) and (1b) differ in important respects. In particular, pronouns are subject to a linearization rule which specifies that pronouns should precede non-pronominal arguments in the medial portion of the German clause (the so-called “middlefield”[2]) independently of their grammatical function. Therefore, a sentence such as (1b) is typically defined as *unmarked* in the sense that it can be

[1] Abbreviations used in the German sentence examples: SUBJ = subject; DOBJ = direct object; IOBJ = indirect object.
[2] The middlefield is defined as the part of a German clause between a complementizer (e.g. *dass*, ‘that’) or a finite verb in second position (cf. example 1) and a clause-final participle, infinitive or particle.

felicitously uttered in the absence of any constraining context (e.g., Siwierska, 1988). In this respect, sentences such as (1b) behave like subject-initial sentences and contrast with sentences involving the permutation of non-pronominal objects (1a), which require contextual licensing. These considerations, which are standard in the theoretical literature on German (Hoberg, 1981; Lenerz, 1977, 1993; Müller, 1995; Wöllstein-Leisten et al., 1997), are also supported by a number of empirical findings using a variety of experimental methods. On the one hand, sentences such as (1a) are judged to be less acceptable than their subject-initial counterparts (e.g., Pechmann et al., 1996; Röder et al., 2000), engender higher activation in the pars opercularis of the left IFG (i.e. a part of Borca's region, Fiebach et al., 2004; Röder et al., 2002) and elicit a left, fronto-central negativity in terms of event-related brain potential (ERP) measures at the position of the permuted object (Bornkessel et al., 2002; Rösler et al., 1998; Schlesewsky et al., 2003). In striking contrast to these findings, the permutation of object pronouns (as in 1b) leads neither to a comparable reduction of sentence acceptability (Bader & Meng, 1999), nor to any ERP effect in comparison to subject-initial control sentences (Schlesewsky et al., 2003). Thus, while pronoun permutation shares all of the domain-general disadvantages for object-initial structures with the permutation of non-pronominal arguments, it is licensed by a language-specific grammatical rule and therefore behaves like a subject-initial structure in terms of linearization properties.

Here, we use the special status of pronouns in German as a diagnostic tool in order to differentiate between the competing factors that have been implicated in the debate on the precise role of Broca’s area during the processing of permuted (complex) sentences. Using functional magnetic resonance imaging (fMRI), we manipulated the factors permutation (permuted vs. non-permuted) and NP-type (first noun phrase pronominal vs. first noun phrase non-pronominal). The critical sentence conditions resulting from this manipulation are shown in Table 1.

Condition	Example
N-SO	Dann I hat I der Lehrer I dem Gärtner I den Spaten I gegeben. then has [the teacher]$_{\text{SUBJ}}$ [the gardener]$_{\text{IOBJ}}$ [the spade]$_{\text{DOBJ}}$ given 'Then the teacher gave the spade to the gardener.'
P-SO	Dann I hat I er I dem Gärtner I den Spaten I gegeben. then has he$_{\text{SUBJ}}$ [the gardener]$_{\text{IOBJ}}$ [the spade]$_{\text{DOBJ}}$ given 'Then he gave the spade to the gardener.'
N-OS	Dann I hat I dem Gärtner I der Lehrer I den Spaten I gegeben. then has [the gardener]$_{\text{IOBJ}}$ [the teacher]$_{\text{SUBJ}}$ [the spade]$_{\text{DOBJ}}$ given 'Then the teacher gave the spade to the gardener.'
P-OS	Dann I hat I ihm I der Lehrer I den Spaten I gegeben. then has him$_{\text{IOBJ}}$ [the teacher]$_{\text{SUBJ}}$ [the spade]$_{\text{DOBJ}}$ given 'Then the teacher gave him the spade.'
COMB	Dann I hat I ihm I den Spaten I der Lehrer I gegeben. then has him$_{\text{IOBJ}}$ [the spade]$_{\text{DOBJ}}$ [the teacher]$_{\text{SUBJ}}$ given 'Then the teacher gave him the spade.'

Table 1: *Critical sentence conditions in the present experiment. Stimulus segmentation is indicated by the vertical bars. Abbreviations used: N = non-pronominal noun phrase; P = pronoun; SO = subject-before-object (non-permuted); OS = object-before-subject (permuted); COMB = combined condition, involving the permutation of both a pronoun and a non-pronominal argument; SUBJ = subject; DOBJ = direct object; IOBJ = indirect object.*

On the basis of the sentence types in Table 1, the following hypotheses can be formulated. Firstly, we expect to replicate previous findings of increased activation in the pars opercularis of the left IFG for the permutation of non-pronominal objects (N-OS) in comparison to subject-initial control sentences (N-SO) (Fiebach et al., 2004; Röder et al., 2002). If this activation is engendered by increased syntactic working memory load in the sense discussed above, permuted pronominal sentences (P-OS) should give rise to a similar activation increase in this region. From the perspective of transformation-based accounts of the function of the left IFG in language comprehension (Ben-Shachar et al., 2003; Ben-Shachar et al., 2004; Grodzinsky, 2000), there are essentially two possibilities. Firstly, if both subject and object pronouns move to a syntactic position reserved for them at the left edge of the middlefield (e.g. Müller, 1999; Haider & Rosengren, 1998), both pronominal conditions (P-SO/P-OS) should be expected to show increased activation as compared to the non-permuted non-pronominal condition (N-SO). A second possibility is that, in accordance with the often assumed ban on string-vacuous movement (Chomsky, 1986), only the object-initial pronominal condition (P-OS) requires a transformation operation while the subject-initial pronominal condition (P-SO) does not. An explanation along these lines would predict a similar activation pattern as the working-memory based account, namely increased activation for the object-initial (P-OS) but not for the subject-initial pronominal condition (P-SO) in comparison to the non-pronominal control (N-SO). Finally, if the IFG activation previously observed reflects the application of language-specific linearization rules that govern the mapping from hierarchical linguistic structure to sequential language input/output (e.g., Bornkessel et al., 2005),[3] the two pronominal conditions (P-SO/P-OS) should both be expected to behave similarly to the non-permuted non-pronominal condition (N-SO) in terms of the activation pattern for this region.

In order to examine possible differences between the permutation of pronominal and non-pronominal arguments more closely, we introduced a further condition involving both (COMB). Here, both the pronoun *ihm* (‘him_{IOBJ}’) and the non-pronominal argument *den Spaten* (‘$[\text{the spade}]_{\text{DOBJ}}$’) precede the subject. On the basis of the results reported by Fiebach et al. (2004), which showed an increase of activation in the left pars opercularis as a function of the number of permutations, we predict that, if pronoun permutation (P-OS) gives rise to increased IFG activation, condition COMB should show higher activation in this region than both conditions N-OS and P-OS. By contrast, if there is no such activation for condition P-OS, condition COMB should behave like condition N-OS.

[3] In fact, the grammatical rule that pronouns should precede non-pronominal arguments is only one of a whole number of principles that govern linear order in the German middle field. While the most important underlying principle at work in this portion of the clause is the argument hierarchy specified by a verb (see above), further modulating principles include, for example, that animate arguments should precede inanimate arguments and that definite arguments should precede indefinite arguments (cf. Lenerz 1977). Essentially, these different factors all encode hierarchical relations between different argument types such that the surface order in the middlefield may be viewed as the output of a mechanism that maps these hierarchical dependencies onto a linear sequence.

8.2 Materials and methods

8.2.1 Participants

Sixteen participants (seven females; mean age: 25.4 years; age range: 21-32 years) took part in the fMRI study. All were monolingual, native speakers of German, had normal or corrected-to-normal vision and were right-handed as assessed by a German version of the Edinburgh Inventory (Oldfield, 1971). Informed written consent was obtained from all participants prior to the scanning session. One further participant was excluded from the final data analysis on account of having consistently failed to respond within the set time limit.

8.2.2 Materials

Participants read 34 sentences in each of the critical conditions in Table 1. All sentences comprised a sentence-initial adverb, followed by a finite auxiliary, three arguments and a clause-final participle. The critical sentences were interspersed with a further 34 ungrammatical sentences in order to balance out the acceptability for the behavioral task (see below). The ungrammatical fillers were of a similar form as the critical sentences but contained an incorrectly positioned participle. As previous studies have shown that sentences involving multiple permutations are judged to be very close to unacceptable on multi-point judgment scales (e.g., Fiebach et al., 2004; Pechmann et al., 1996; Röder et al., 2000), participants were thus confronted with 102 acceptable sentences (conditions N-SO, P-SO and P-OS), 68 sentences of a markedly degraded acceptability (condition COMB and the filler sentences) and 34 sentences of medium acceptability (condition N-OS). Finally, 34 null events (empty trials) were introduced in order to improve the statistical evaluation of the data (Miezin et al., 2000), thus resulting in a total number of 238 trials per participant.

8.2.3 Procedure

Participants read the experimental sentences via LCD goggles (Visuastim, Magnetic Resonance Technology, Northridge, CA). In order to control for reading strategies, sentences were presented in a segmented manner, with a presentation time of 400 ms per segment and an inter-stimulus interval (ISI) of 100 ms (segmentation indicated in Table 1). Each trial began with the presentation of an asterisk (300 ms plus 200 ms ISI) and ended with a 500 ms pause, after which a question mark signaled to participants that they should judge the acceptability of the preceding sentence. The participants performed the judgment task by pressing one of two push-buttons with their right index and middle fingers and were given maximally 2500 ms to respond. The assignment of fingers to acceptable and unacceptable was counterbalanced across participants.

Trials were presented with variable onset delays of 0, 400, 800, 1200 or 1600 ms, thereby leading to an oversampling of the actual image acquisition time of 2000 ms by a factor of 5 (Miezin et al., 2000). All trials had a length of 8 s, thus resulting in a total measurement time of 32 minutes, which was separated into two functional runs. Each participant completed a short practice session before entering the scanner.

8.2.4 fMRI data acquisition

The experiment was carried out on a 3T scanner (Medspec 30/100, Bruker, Ettlingen). Twenty axial slices (19.2 cm FOV, 64 by 64 matrix, 4 mm thickness, 1 mm spacing), parallel to the AC-PC plane and covering the whole brain were acquired using a single shot, gradient recalled EPI sequence (TR 2000 ms, TE 30 ms, 90° flip angle). Two functional runs of 476 time points were collected, with each time point sampling over the 20 slices. Prior to the functional runs, 20 anatomical T1-weighted MDEFT (Ugurbil et al., 1993; Norris, 2000) images (data matrix 256x256, TR 1.3 s, TE 10ms) and 20 T1-weighted EPI images with the same geometrical parameters as the functional data were acquired.

8.2.5 fMRI data analysis

The fMRI data were analyzed using the LIPSIA software package (Lohmann et al., 2001), which contains tools for preprocessing, registration, statistical evaluation and presentation of fMRI data.

Functional data were corrected for motion using a matching metric based on linear correlation. To correct for the temporal offset between the slices acquired in one scan, a cubic-spline-interpolation based on the Nyquist-Shannon-Theorem was applied. A temporal highpass filter with a cutoff frequency of 1/112 Hz was used for baseline correction of the signal and a spatial Gaussian filter with 5.65 mm FWHM was applied.

To align the functional data slices onto a 3D stereotactic coordinate reference system, a rigid linear registration with six degrees of freedom (3 rotational, 3 translational) was performed. The rotational and translational parameters were acquired on the basis of the MDEFT and EPI-T1 slices to achieve an optimal match between these slices and the individual 3D reference data set. This 3D reference data set was acquired for each subject during a previous scanning session. The MDEFT volume data set with 160 slices and 1mm slice thickness was standardized to the Talairach stereotactic space (Talairach & Tournoux, 1988). The same rotational and translational parameters were normalized, i.e., transformed to a standard size via linear scaling. The resulting parameters were then used to transform the functional slices using trilinear interpolation, so that the resulting functional slices were aligned with the stereotactic coordinate system. This linear normalization process was improved by a subsequent processing step that performs an additional non-linear normalization (Thirion, 1998).

The statistical evaluation was based on a least-squares estimation using the general linear model for serially autocorrelated observations (see also Friston et al., 1995; Worsley & Friston, 1995; Aguirre et al., 1997; Zarahn et al., 1997). The design matrix was generated with a box-car function convolved with the hemodynamic response function. The model equation, including the observation data, the design matrix and the error term, was convolved with a Gaussian kernel of dispersion of *4 sec. FWHM* to deal with the temporal autocorrelation (Worsley & Friston, 1995). Contrast maps were then generated for each subject. As the individual functional datasets were all aligned to the same stereotactic reference space, a group analysis was performed. The single-participant contrast-images were entered into a second-level random effects analysis for each of the contrasts. The group analysis consisted of a one-sample t-test across the contrast images of all subjects that indicated whether observed differences between conditions were significantly distinct from zero (Holmes & Friston, 1998). Subsequently, *t* values were transformed into *Z* scores. To protect against false positive activations, only regions with a *Z* score greater than 3.1 ($p < 0.001$ uncorrected) and with a volume greater than 216 mm^3 (6 measured voxels) were considered (Braver & Bongiolatti, 2002; Forman et al., 1995).

8.3 Results

8.3.1 Behavioral data

The mean acceptability ratings and reaction times collected in the behavioral task are shown in Figure 1 for each of the critical conditions.

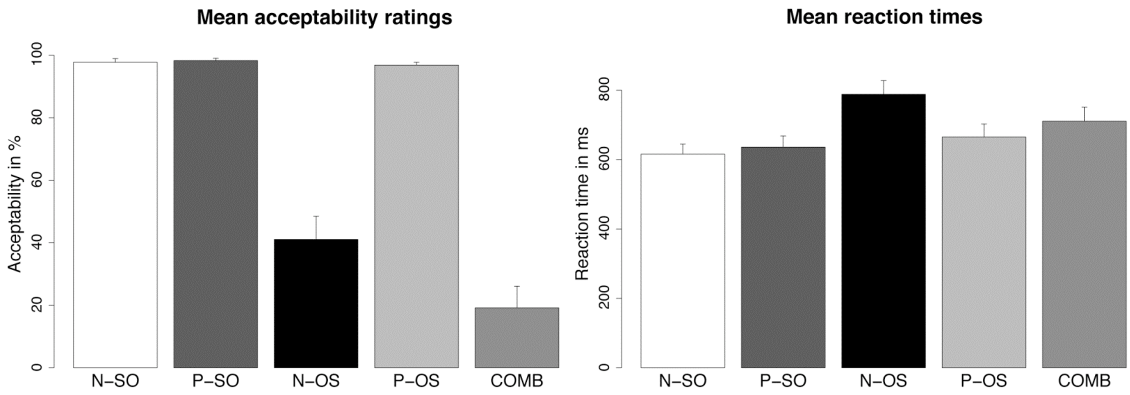

Figure 1: *Mean acceptability ratings and reaction times for each of the critical sentence conditions. Error bars indicate the standard error of the mean.*

For the statistical analysis of the behavioral data, we first computed one-way repeated measures analyses of variance (ANOVA) involving the factor condition (COND). When the main effect of COND reached significance, we tested for possible differences between the critical conditions and the non-permuted, non-pronominal control (N-SO) by computing planned comparisons between the control condition and each of the other four conditions. Furthermore, in order to examine possible differences among the permuted conditions, we also compared the combined condition (COMB) with the non-pronominal permuted condition (N-OS) and the pronominal permuted condition (P-OS). The probability levels for planned comparisons were adjusted according to a modified Bonferroni procedure (Keppel, 1991).

With regard to the acceptability ratings, the global analysis showed a main effect of COND (F (4,60) = 88.90; $p < .001$). The subsequent planned comparisons revealed significant differences for the permuted, non-pronominal condition (N-OS; F (1,15) = 62.64; $p < .001$) and the combined condition (COMB; F (1,15) = 62.64; $p < .001$) in comparison to the control (N-SO). The two pronominal conditions (P-SO and P-OS), by contrast, did not differ significantly from N-SO ($F < 1$). The comparisons among the permuted conditions showed significant differences between COMB and N-OS (F (1,15) = 43.94, $p < .001$) and COMB and P-OS (F (1,15) = 133.46, $p < .001$).

For the analysis of the reaction times, the main effect of COND also reached significance (F (4,60) = 13.81; $p < .001$). Here, all conditions differed significantly from the control (P-SO vs. N-SO: F (1,15) = 6.44, $p < .05$; N-OS vs. N-SO: F (1,15) = 39.69, $p < .001$; P-OS vs. N-SO: F (1,15) = 10.40, $p < .01$; COMB vs. N-SO: F (1,15) = 8.66, $p < .05$). However, there were no significant differences for COMB vs. N-OS ($p > .26$) and COMB vs. P-OS ($p > .19$).

The acceptability rates are in line with the theoretical assumptions concerning the experimental manipulation. While the permuted non-pronominal condition (N-OS) was judged to be significantly less acceptable than the control condition (N-SO), no such acceptability decrease was observable for either of the pronominal conditions (P-SO/P-OS). The comparable acceptability for permuted pronominal structures and non-permuted non-pronominal structures thus provides converging support for the claim that pronoun permutation is an unmarked operation in German, because it is licensed by an independent rule governing the positioning of pronouns. Finally, the acceptability ratings also showed that the combined condition, which involved two permutation operations, is less acceptable than the two conditions including single permutations.

As for the differences in reaction times, these are somewhat difficult to interpret because participants were only responding under very moderate time pressure (cf., for example, Bornkessel et al., 2004). Nonetheless, a cautious association of the increased reaction times for all non-control conditions with higher processing load or decision difficulty is consistent with the assumptions underlying the present experimental manipulation. Thus, the acceptability decreases for both the single non-pronominal permuted condition (N-OS) and the combined condition (COMB) were mirrored in increased reaction times. The reaction time increase for the pronominal permuted condition (P-OS) may, on the one hand reflect the fact that this condition also engendered increased syntactic working memory costs in comparison to the control condition. Alternatively, however, the reaction time increase for condition P-OS might stem from more general processes applying to the pronominal sentences, because reaction times were also longer for the non-permuted condition (P-SO) in comparison to the non-pronominal control (N-SO). From this perspective, the general latency increase for the pronoun conditions could reflect the additional difficulties associated with judging as acceptable a sentence with a pronoun that has no antecedent.

8.3.2 fMRI data

In order to identify the neural network sensitive to argument permutation, we firstly computed a direct contrast between the permuted and non-permuted non-pronominal conditions (N-OS vs. N-SO). The activations observable in this contrast are shown in Figure 2 and Table 2.

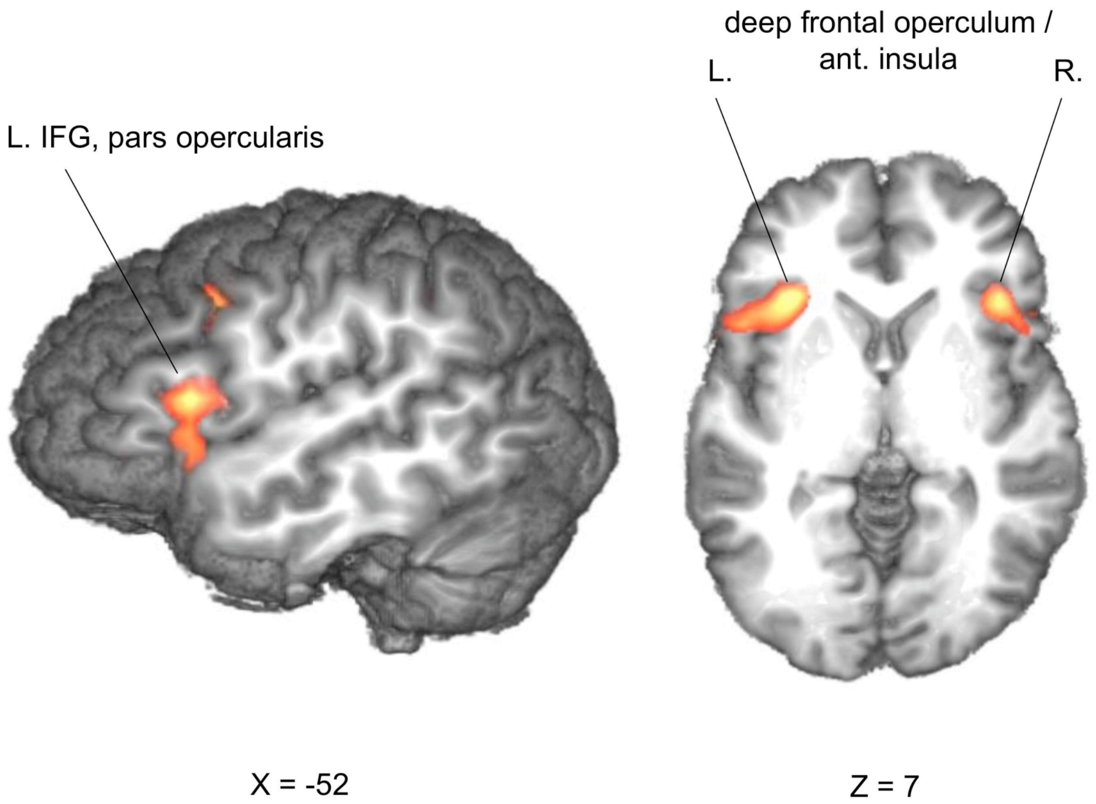

Figure 2: *Averaged activation with a z-value > 3.1 for the contrast between the non-pronominal permuted condition (N-OS) and the control condition (N-SO).*

Region	Talairach coordinates	Max. z-value	Volume (mm^3)
L. deep frontal operculum / anterior insula	-32 20 3	4.75	5297
L. inferior frontal gyrus (IFG), pars opercularis	-52 14 15	4.44	----
L. frontomedian cortex (pre-SMA / BA 8)	-2 32 30	4.13	4384
L. inferior frontal junction area (IFJ)	-38 8 38	4.53	1309
R. inferior frontal sulcus (IFS)	44 26 18	4.05	638
R. deep frontal operculum / anterior insula	38 20 6	4.31	2070
R. inferior frontal gyrus (IFG), pars opercularis	46 11 9	3.97	----

Table 2: *Talairach coordinates, maximal z-values and volumes of the activated region for the local maxima in the contrast between permuted non-pronominal (N-OS) and non-permuted non-pronominal sentences (N-SO). Only activations with a z-value > 3.09 and a volume of at least 216 mm^3 (6 measured voxels) were considered. Local maxima were defined as the largest z-value exceeding 3.09 within a 10 mm radius.*

As is apparent from Figure 2 and Table 2, the present study replicates previous findings on the permutation of non-pronominal arguments in German (Fiebach et al., 2004; Röder et al., 2002) in showing increased bilateral pars opercularis activation for permuted structures. Here, this activation extended into the deep frontal operculum/anterior insula. Further activations were observed in the frontomedian cortex (pre-SMA/BA 8), the left inferior frontal junction area (IFJ) and the right inferior frontal sulcus (IFS).

In order to examine the differences between conditions with respect to the hypotheses formulated in the introduction, we extracted the time course of the underlying BOLD signal for the regions shown in Table 2. Within these regions, the percent signal change for the voxel with the highest z-value and the 26 adjacent voxels (relative to the mean signal intensity over all timepoints per voxel) was averaged for each condition and participant, with subsequent averaging over all 16 participants. The time course of the null events was subtracted from the averaged single-event time courses for the critical sentence conditions (Burock et al., 1998). Figure 3 visualizes the results of the time course analysis by showing the mean percent signal change in a time window from 8 to 12 s post sentence onset for each of the critical conditions.

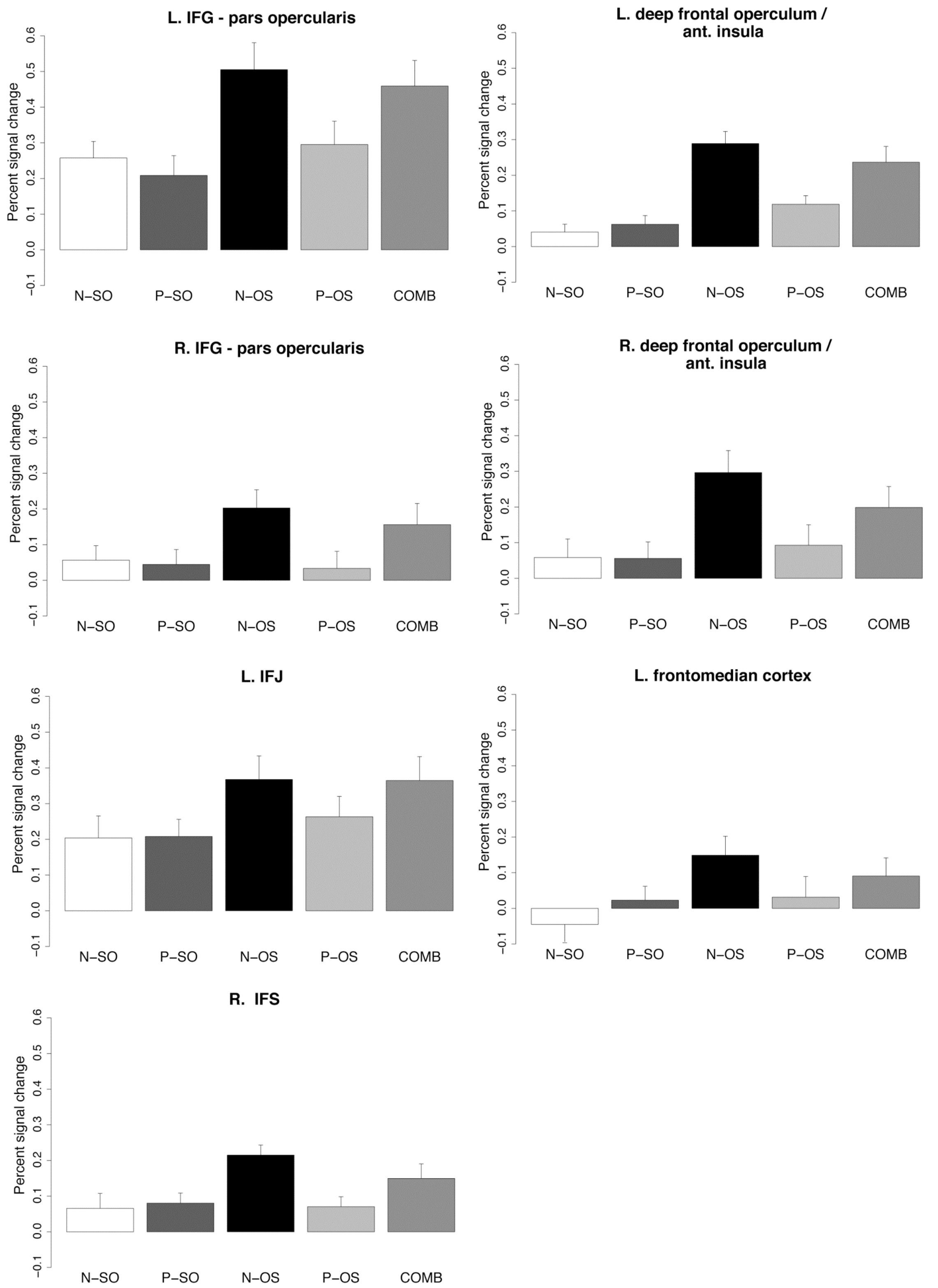

Figure 3: *Average percent signal change (8 to 12 s relative to sentence onset) for regions showing a significant effect of permutation for the non-pronominal conditions (N-OS vs. N-SO). Error bars indicate the standard error of the mean.*

The averaged time courses were subjected to repeated measures analyses of variance (ANOVAs) involving the factor condition (COND). The results of this analysis are summarized in Table 3, as are the planned comparisons between individual conditions for those regions showing a main effect of COND. The significance level of the planned comparisons was adjusted according to a modified Bonferroni procedure (Keppel, 1991).

Region	COND	P-SO vs. N-SO	N-OS vs. N-SO	P-OS vs. N-SO	COMB vs. N-SO	COMB vs. P-OS	COMB vs. N-OS
L. IFG (pars opercularis)	*** (9.83)	n.s.	*** (19.74)	n.s.	* (9.84)	* (6.06)	n.s.
L. deep frontal operculum / ant. insula	*** (18.64)	n.s.	*** (55.09)	m. (5.53)	*** (22.18)	* (7.33)	n.s.
R. IFG (pars opercularis)	*** (6.91)	n.s.	*** (19.64)	n.s.	* (6.23)	m. (5.45)	n.s.
R. deep frontal operculum / ant. insula	*** (10.92)	n.s.	*** (27.57)	n.s.	* (9.25)	n.s.	n.s.
L. frontomedian cortex	*** (7.08)	n.s.	*** (34.81)	n.s.	** (10.29)	n.s.	n.s.
L. IFJ	*** (12.30)	n.s.	*** (33.63)	* (5.63)	** (16.02)	* (8.06)	n.s.
R. IFS	*** (9.26)	n.s.	*** (26.97)	n.s.	* (9.74)	* (8.04)	* (8.94)

Table 3: *Summary of the global statistical analysis for the averaged percent signal change for the voxel with the maximal activation and the 26 adjacent voxels in each of the regions showing a significant effect of permutation for the non-pronominal conditions (N-OS vs. N-SO). Each cell gives the significance level for an effect (n.s. = not significant; m. = marginal ($p < .07$); * = $p < .05$; ** = $p < .01$; *** = $p < .001$) and the F-value for significant effects. Degrees of freedom were $df_1 = 4$, $df_2 = 60$ for the global analysis involving the factor COND and $df_1 = 1$, $df_2 = 15$ for the planned comparisons. The probability levels for the planned comparisons are Bonferroni-corrected.*

The analyses summarized in Table 3 show that, in the pars opercularis of the left IFG, the permuted non-pronominal (N-OS) and the combined (COMB) conditions engender increased activation in comparison to the control (N-SO). By contrast, neither the non-permuted (P-SO) nor the permuted pronominal condition (P-OS) differs significantly from the control condition in this region. Finally, the combined condition (COMB) shows significantly more activation than N-SO and P-OS, but does not differ from N-OS.

Similar activation patterns were observed in the right hemisphere homologue of the pars opercularis and in the left deep frontal operculum/anterior insula. By contrast, the right deep frontal operculum/anterior insula and left frontomedian cortex failed to show a significant difference between COMB and P-OS, while the right IFS showed a significant difference between COMB and N-OS and the left IFJ responded more strongly to the P-OS than to the N-SO condition.

8.4 Discussion

The present study aimed to shed light on the precise role of the pars opercularis of the IFG in the processing of permuted (complex) word orders by examining permuted German sentences that behave like subject-initial (non-permuted) sentences. With regard to the permutation of non-pronominal arguments, this study replicated previous findings of increased bilateral activation in the pars opercularis of the IFG. In contrast to earlier experiments, however, this activation additionally extended into the deep frontal operculum/anterior insula. Crucially, the permutation of *pronominal* arguments did not lead to an activation increase in these cortical regions in comparison to the non-pronominal, subject-initial control condition. Similarly, the subject-initial pronominal condition also did not show an activation increase. Finally, the combined condition, which involved the permutation of a pronominal and a non-pronominal argument, behaved like the single non-pronominal permutation in terms of pars opercularis activation, engendering increased activation in comparison to both the non-permuted, non-pronominal control and the permuted pronominal condition. In the following, we will discuss the implications of these findings for the different accounts regarding the function of the pars opercularis – and, more generally, of Broca's area – during the comprehension of permuted (complex) sentences.

8.4.1 Broca's region, language and working memory

As discussed in the introduction, in terms of syntactic working memory costs, the permuted pronominal condition should behave similarly to the non-pronominal permuted condition, because the lower-ranking argument in the argument hierarchy of the verb must be maintained until the higher-ranking argument(s) have been processed (Gibson, 1998; Kaan & Swaab, 2002). Thus, if the role of Broca's area – or, more precisely, of the pars opercularis of the left IFG – in language processing is crucially tied to working memory resources (e.g., Caplan et al., 2000; Fiebach et al., 2005), the permuted pronominal condition (P-OS) should show a similar activation increase in comparison to the non-permuted non-pronominal condition (N-SO) as the permuted non-pronominal condition (N-OS). However, this was not the case: the permuted pronominal condition did not differ from the non-permuted non-pronominal condition in this region. In this way, these findings indicate that working memory is not the decisive factor involved in the increased pars opercularis activation during the processing of complex sentences.[4] Rather, the data call for a language-specific explanation.

8.4.2 Broca's region, language and transformations

Perhaps the most prominent language-inherent account of Broca's area activation during the processing of complex (permuted) sentences is the transformation-based hypothesis put forward by Grodzinsky (2000) and Ben-Shachar et al. (2003, 2004). However, while this type of account can derive previous findings on argument permutation in German and various other languages, the present findings speak against a transformation-based explanation of word order-based activations of Broca's region.

As was laid out in the introduction, transformation-based accounts can essentially derive two possible predictions with respect to the positioning of pronouns in German. Firstly, it has been assumed that pronouns must generally – i.e. independently of their grammatical function – undergo a dislocation from the position determined by the argument structure of the verb to the left edge of the German middlefield (e.g., Haider & Rosengreen, 2003; Lenerz, 1977; Müller, 1998; cf. also Schlesewsky et al., 2003). From this perspective, both of the pronominal conditions (P-SO/P-OS) involve a transformation as compared to the non-pronominal control condition (N-SO). Thus, in terms of a transformation-based account, *both* should be expected to show increased activation in Broca's area, as argued, for example, by Ben-Shachar et al. (2004) for both subject- and object-initial wh-questions in comparison to yes-no questions in Hebrew. With regard to the present study, the time course analysis showed that this hypothesis is not borne out, because neither of the two pronominal conditions engenders increased activation in Broca's area in comparison to the non-pronominal, non-permuted control.

[4] Of course, this explanation does not exclude that working memory-based processes are involved in the comprehension of sentences with permuted pronominal arguments, and, indeed, we would assume that these processes are certainly required in order for such sentences to be understood successfully. Nonetheless, different demands on working memory cannot account for the contrast between pronominal and non-pronominal permutation.

A second possibility is that only the object-initial pronominal condition requires a transformation, while the subject-initial pronominal condition (P-SO) does not. From the perspective of this analysis, and assuming the transformational account, only the object-initial (P-OS) condition should be expected to show increased activation in comparison to the non-pronominal control (N-SO). Again, the results of the present study are incompatible with such an account, because there is no increased IFG activation for P-OS in comparison to N-SO.

One final possibility in order to salvage the transformation-based account would be to assume that pronouns are simply "inserted" (or base generated) at the left edge of the middlefield independently of their grammatical function. Yet this possibility not only appears stipulated in view of the absence of independent evidence in its favor. It is also undesirable from a theoretical perspective because it would result in the abandonment of one of the most fundamental assumptions of the form-to-meaning mapping that lies at the core of language. Thus, it is generally assumed that a verb's lexical entry contains a hierarchical representation of its arguments, which essentially corresponds to the relations holding between the arguments' participant roles (e.g., Baker, 1988; Perlmutter, 1978; Van Valin & LaPolla, 1997; Wunderlich, 1997). In basic, non-permuted sentences, the syntactic structure directly reflects this lexical argument hierarchy, thus guaranteeing the correspondence between meaning and form. Indeed, the very concept of transformations is based on this assumption, because if the form-to-meaning mapping could be achieved by other means, there would be no need to reconstruct a surface ordering to an underlying ordering. Thus, the present activation pattern does not appear to derive from the differential application of transformation operations.

8.4.3 Broca's region and sentence acceptability

One of the critical properties of the permuted pronominal sentences is that their acceptability is in no way degraded in comparison to that of non-permuted sentences (97% as opposed to 41% for the permuted non-pronominal sentences in the present study). Thus, at a first glance, the pattern of pars opercularis activation observed here might appear to mirror the surface acceptability of the structures under examination.

However, several observations indicate that the pars opercularis activation for permuted sentences does not simply mirror sentence acceptability. Firstly, consider the results of a previous study contrasting grammatical and ungrammatical sentences in German (Fiebach et al., 2004). This study employed very complex, but nonetheless grammatical structures involving the permutation of two non-pronominal objects. Due to the high complexity of these structures, they are reliably rated as unacceptable by linguistically naïve participants (cf., Pechmann et al., 1996; Röder et al., 2000). However, despite the overtly comparable degree of (un)acceptability of the complex and ungrammatical sentences, the two types of structures engendered distinct patterns of activation in inferior frontal cortex: while the complex, grammatical condition gave rise to increased activation of the inferior portion of the pars opercularis of the IFG, the ungrammatical condition resulted in a stronger activation of the posterior deep frontal operculum. This dissociation suggests that it is not acceptability *per se* that covaries with the activation of the pars opercularis.

Upon closer consideration, the findings of the present study also preclude an explanation in terms of acceptability. Consider the behavior of the combined condition (COMB), which involved the permutation of both a pronoun and a non-pronominal argument. The acceptability of this condition was significantly lower than that of the condition with a single permuted non-pronominal argument (N-OS) (19% vs. 41%). An acceptability-based account of the pars opercularis activation observed here should therefore also predict increased activation for condition COMB in comparison to condition N-OS. However, as is apparent from the averaged signal timecourses in Figure 3 and from the statistical analyses in Table 3, there was no difference between these two conditions in the pars opercularis. In this way, the relationship between sentence acceptability and pars opercularis activation is not one-to-one and the activation patterns therefore call for a more principled explanation.

8.4.4 Broca's region and the linearization of linguistic hierarchies

As discussed above, the pattern of pars opercularis activation in the present experiment appears derivable *neither* in terms of general properties such as working memory requirements or sentence acceptability *nor* as a function of (language-inherent) transformation operations. Rather, we propose that the present findings are most naturally accounted for in terms of a model assuming that the pars opercularis of the IFG engages selectively in the linearization of hierarchical linguistic dependencies (see also Bornkessel et al., 2005). Hierarchical dependencies of various types abound in natural language; for example, objects may be viewed as hierarchically dependent on subjects (at least in European languages) because all syntactic operations that can affect objects can also affect subjects but not vice versa. Similarly, in terms of the conceptual relationship holding between sentential arguments, arguments that are Undergoers of an event are typically thought to be dependent upon arguments that are Actors, because the event that causes the Undergoer to be affected must have been caused by some other participant (the Actor). Due to the sequential nature of language, such dependencies often map onto linearization preferences such that subjects preferentially precede objects and Actors preferentially precede Undergoers, for example. Note also that, while these linearization principles often correlate with frequency of occurrence, this need not be the case, thus suggesting that the preferences in question cannot be reduced to structural frequency (e.g., Bornkessel et al., 2002; Schlesewsky et al., 2003).

Despite certain tendencies that are shared across languages, linearization principles are generally language-specific. Thus, from this perspective, it is not surprising that there are sentences in German in which the preference for subjects to precede objects is overridden by a further linearization rule specific to this language, namely that pronouns should precede non-pronominal arguments in the middlefield. This second principle therefore licenses pronoun-initial orders even when the pronoun is an object and precedes the (non-pronominal) subject. Under the assumption that the pars opercularis of the left IFG is sensitive to such linearization principles, the absence of increased activation in the permuted pronoun condition as compared to the non-pronominal control condition is straightforwardly derivable.

A possible theoretical foundation for such a linearization-based account of pars opercularis function lies in Jackendoff's (2002) tripartite language architecture. This model assumes parallel representations for syntactic, semantic and phonological information, which then interact with one another at so-called *interface levels*. Word order permutations arise when the syntax permits different possible orderings and the optimal linearization is determined at the interfaces (e.g. by semantic information such as animacy or phonological information such as constituent "weight"). From this perspective, the pars opercularis could be viewed as engaging in interface-level functions, which integrate several different information types in order to evaluate potential sequential orderings.

8.4.5 The role of the deep frontal operculum / anterior insula

In contrast to previous findings, the activation associated with argument order permutations in the present study was not confined to the lateral surface of the pars opercularis, but rather extended into the deep frontal operculum / anterior insula. This observation raises two important questions, namely (a) whether these adjacent cortical regions perform similar or distinct functions, and (b) why previous studies did not report the deep fronto-opercular/insular activation.

With regard to possible distinct functions of the pars opercularis and the deep frontal operculum, it has recently been suggested that the former engages in the processing of complex (permuted) sentences while the latter is crucially involved in the detection of ungrammaticality (Friederici, 2004). This hypothesis was based on a number of empirical findings showing activation of the deep frontal operculum rather than of the IFG in response to ungrammatical sentences (Fiebach et al., 2004; Friederici et al., 2003; Kuperberg et al., 2000). By contrast, the present study failed to reveal systematic differences between the activation pattern of the pars opercularis and that of the deep frontal operculum. Moreover, neither of these regions showed a direct correlation with sentence acceptability.

Alternatively, the activation differences observed in the deep frontal operculum / anterior insula in the present study as opposed to previous findings (Fiebach et al., 2004; Röder et al., 2002) might be attributable to more general processes involved in the evaluation of linguistic structures. In particular, the involvement of anterior insular cortex may be telling in this respect. As part of the paralimbic system, the anterior insula is involved in the mediation of subjective feeling states (cf., Craig, 2002) and reacts to changes in the state of autonomic arousal (e.g., Critchley et al., 2001). However, a number of studies have also implicated an involvement of the anterior insula in decision-making in the presence of uncertainty (e.g., Paulus et al., 2001; Ullsperger & von Cramon, 2001; Volz et al., 2004). Linking this to the present experimental paradigm, recall that the permuted non-pronominal stimuli used here are possible in German, but of degraded acceptability. Thus, sentences of this type are perceived by speakers neither as perfectly well-formed nor as fully impossible, thereby rendering the degree of uncertainty associated with a two-way forced choice judgment much higher. Moreover, because constructions of this type are often considered poor style in prescriptive grammars of German, participants were instructed that they should judge the sentences on the basis of their own linguistic intuition and that there are no right and wrong answers. Note that this mode of instruction also differs from those employed in previous studies, in which participants were asked to judge whether sentences were "grammatical" or "ungrammatical". As such, the environment for the present judgment task – and particularly for the conditions involving the permutation of a non-pronominal object – was one of high uncertainty.

Possibly, then, the deep fronto-opercular/anterior insular activation observed here may have resulted from the involvement of partly intuitive evaluative decision mechanisms that apply in the absence of any clear rule-system on which responses might be based. An explanation along these lines accounts for (a) why the activation of the deep frontal operculum was not observed in previous studies that did not employ an explicit judgment task, and (b) why there is no direct correlation between the activation of this region and surface sentence acceptability (i.e. the level of acceptability of a particular sentence structure is in principle independent of the ease or difficulty involved in making this judgment). Nonetheless, the present results indicate that the precise role of the deep frontal operculum/anterior insula in linguistic judgments remains an important topic for future research.

8.5 Conclusions

The present study set out to distinguish between several competing accounts regarding the function of Broca's area – and particularly the pars opercularis of the left IFG - during the processing of complex (permuted) sentences. By employing permuted German sentences that behave like simple, subject-initial sentences, we were able to show that permutation *per se* does not engender increased activation in this region. Thus, the predictions of working memory-based and transformation-based accounts of Broca's area function are not borne out. Rather, our results suggest that the pars opercularis is selectively sensitive to the language-specific linearization of hierarchical linguistic dependencies, a proposal that not only accounts for the present findings, but also derives previously reported cross-linguistic differences in the activation of Broca's region.

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Appendix

Curriculum Vitae

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Abstract (English)

Animacy makes a fundamental contribution to the categorization of everyday experiences. In this way, the differentiation between animate and inanimate entities is important for the identification of potentially more or less causative characters. With respect to the language system, animacy is a semantic feature of universal importance. Cross-linguistic research revealed a three-tiered animacy hierarchy: Human > Animate > Inanimate. This animacy hierarchy is reflected by different linguistic properties depending on the language under consideration. In some languages, animacy information has an influence on word order (e.g. German, Finnish), in others case marking is morphologically determined by this feature, and an effect of animacy on sentence interpretation can be observed (e.g. Fore, Hindi).

The aim of the present thesis is to shed light on the impact of animacy on sentence processing in German. Although animacy is a purely semantic feature, an influence of this parameter on syntactic structure has been observed such that animate arguments should precede inanimate arguments within the German middle field (e.g. *Gestern wurde dem Redakteur der Artikel präsentiert;* yesterday was [the editor]$_{\text{A-OBJ}}$ [the article]$_{\text{I-SUBJ}}$ presented). Since German is a language with flexible word order, the order of the two arguments can also be changed, as demonstrated in the sentence *Gestern wurde der Artikel dem Redakteur präsentiert;* yesterday was [the article]$_{\text{I-SUBJ}}$ [the editor]$_{\text{A-OBJ}}$ presented. Although both sentences are grammatically correct, the linearization of arguments within the latter sentence is unexpected with respect to animacy. Nevertheless, this sentence reflects the preferred subject-before-object order which is violated in the first example. As the examples demonstrate, the animacy principle is one of several language-specific linearization principles whose influence on argument order cannot always be clearly differentiated.

Besides the influence of animacy on the linearization of arguments, this feature is also interesting from a relational point of view. The most natural kind of a transitive sentence comprises an information flow from the causer of an event which is high in animacy to the argument that is lower in animacy and agency. Besides this unmarked transitive sentence structure, German also allows for an asymmetrical and therefore less natural distribution in which either both arguments are animate (*Gestern hat der*

Redakteur den Mitarbeiter entdeckt, yesterday has [the editor]$_{A\text{-}SUBJ}$ [the colleague]$_{A\text{-}OBJ}$ discovered) or the assignment of animacy is even completely reversed (*Gestern hat der Artikel den Redakteur überrascht*, yesterday has [the article]$_{I\text{-}SUBJ}$ [the editor]$_{A\text{-}OBJ}$ surprised). However, such asymmetrical distributions are supposed to result in deviations from the unmarked transitive sentence structure indicating that the relation between sentential arguments at least partially depends on their animacy.

Since previous behavioral and neurophysiological data provided evidence for an influence of animacy in syntactic processing the present work aims to examine neuroanatomical correlates of this semantic feature. This thesis reports three experiments investigating both the influence of animacy on the linearization of word order and its relational effect in sentence processing. Thereby, functional magnetic resonance imaging was used as a research method.

Regarding the influence of animacy on the linearization of arguments, a sensitivity of the pars opercularis of the left inferior frontal gyrus (IFG) to violations of the animacy principle was demonstrated. In contrast to former accounts on the functional role of the pars opercularis that interpreted its sensitivity to complex sentence structures in terms of syntactic transformations or syntactic working memory costs, the present thesis provides strong evidence for a language-specific function of this region in the linearization of arguments. Thus, an activation increase in the pars opercularis was not only found when the syntactic linearization principle was violated (subject-before-object principle) but also when a principle concerning syntactic and semantic information was violated (thematic hierarchy principle) and even in case of violations of a purely semantic linearization principle (animacy principle).

Furthermore, the posterior superior temporal sulcus (pSTS) of the left hemisphere was shown to engage in the processing of unmarked transitivity, which can be attributed to the relational impact of animacy information. Independent of argument order, there was always an activation increase in this cortical region when the critical sentences contained two animate arguments, thereby yielding an interpretation in terms of the relational role of animacy. This second experimental result is consistent with previous neuroanatomical data indicating an engagement of this cortical region when a mapping between syntactic and semantic argument hierarchies was not straightforwardly possible. Obviously, the pSTS can be associated with the interaction between syntactic and semantic information, in which the animacy of the arguments is of crucial importance with respect to their relation.

Altogether, the present neuroanatomical data provide clear evidence for an influence of the semantic feature animacy on sentence processing. It is shown for the first time that a cortical region which has previously been exclusively associated with syntactic processing is also sensitive to this non-syntactic feature. In addition to the investigation of specific linguistic questions, an empirical approach like the present provides the opportunity for a more fine-grained development of sentence processing models on the basis of behavioral, neurophysiological and neuroanatomical data.

Abstract (German)

Das Konzept der Belebtheit nimmt eine grundlegende Rolle in der höheren Kognition ein. So hilft die Fähigkeit zur Differenzierung zwischen *belebten* und *unbelebten* Entitäten bei der Einschätzung potentiell mehr oder weniger kausativer Charaktere eines Ereignisses. In der Sprache stellt die Belebtheit ein semantisches Merkmal von universaler Gültigkeit dar, welches sich in eine dreistufige Hierarchie untergliedern lässt: Menschlich > Belebt > Unbelebt. Diese sogenannte Belebtheitshierarchie zeigt sich in einer Vielzahl von Sprachen auf ganz unterschiedliche Weise. Während sich Belebtheitsunterschiede in manchen Sprachen auf die Wortstellung im Satz auswirken (z.B. Deutsch, Finnisch), determinieren sie in anderen sogar die morphologische Kasusmarkierungen von Argumenten und beeinflussen damit auch die Interpretation der Argumente im Satz (z.B. Hindi, Fore).

Die vorliegende Dissertation beschäftigt sich mit dem neurokognitiven Sprachverstehen und untersucht den Einfluss des Parameters Belebtheit auf der Satzebene im Deutschen. So kann im deutschen Mittelfeld eine generelle Tendenz beobachtet werden, belebte vor unbelebten Argumenten zu realisieren. Dieses semantische Merkmal hat also offensichtlich einen Einfluss auf die syntaktische Struktur, wie aus dem Satz *Gestern wurde dem Redakteur der Artikel präsentiert* ersichtlich wird. Aufgrund der relativ freien Wortstellung kann natürlich auch eine Umstellung dieses Satzes erfolgen. Diese geht mit einer Verletzung des Belebtheitsprinzips einher, zeigt dafür aber die ansonsten präferierte Subjekt-vor-Objekt Reihenfolge (*Gestern wurde der Artikel dem Redakteur präsentiert).* Das Belebtheitsprinzip ist eines von verschiedenen sprachspezifischen Linearisierungsprinzipien, deren Einfluss auf die Wortstellung nicht immer eindeutig voneinander abzugrenzen ist.

Neben dem Einfluss der Belebtheit auf die Wortstellung im Satz, werden auch relationale Eigenschaften dieses Merkmals untersucht. In einem unmarkierten transitiven Satz wird ein Informationsfluss von einem belebten Argument, welches eine Handlung verursacht, zu einem unbelebten Argument, welches diese Handlung erfährt, erwartet. Beinhaltet ein Satz jedoch zwei belebte Argumente (*Gestern hat der Redakteur den Mitarbeiter entdeckt)* oder ein unbelebtes Argument, welches thematisch

höher steht als das belebte Argument (*Gestern hat der Artikel den Redakteur überrascht)*, so führt dies zu einer veränderten Relation zwischen beiden beteiligten Argumenten und gleichzeitig zu einer Verletzung der unmarkierten Transitivität in der Verb-Argument-Interaktion.

Nachdem erste empirische Daten (behavioral und neurophysiologisch) einen frühen Einfluss des semantischen Belebtheitsmerkmals auf die Verarbeitung syntaktischer Strukturen indiziert haben, deckt die vorliegende Arbeit neuroanatomische Korrelate der Belebtheit auf. Vorgestellt werden drei Experimente zum Satzverstehen, in denen sowohl die Interaktion von Belebtheit und Wortstellung als auch der relationale Einfluss von Belebtheit untersucht wurden. Als Untersuchungsmethode wurde die funktionelle Magnetresonanztomographie gewählt.

Im Hinblick auf den Einfluss von Belebtheit im Satzverstehen kann zum einen gezeigt werden, dass im pars opercularis des linken Gyrus inferior frontalis (IFG) eine Sensitivität für den Einfluss dieses semantischen Merkmals auf die Reihenfolge der Argumente im Mittelfeld besteht. Im Gegensatz dazu wurde diese kortikale Region im linken IFG bislang hauptsächlich mit der Verarbeitung komplexer syntaktischer Strukturen assoziiert, wobei angenommen wurde, dass syntaktische Bewegung zu einem erhöhten Verarbeitungsaufwand im Sinne syntaktischer Operationen und eines syntaktischen Arbeitsgedächtnisses führt. Ergebnisse der vorliegenden Arbeit stärken jedoch die Annahme, dass der pars opercularis im linken IFG sensitiv für sprachspezifische Linearisierungsregeln ist, die nicht nur syntaktischer Natur sind (Subjekt-vor-Objekt Prinzip) sondern z.B. auch einen Bereich zwischen Syntax und Semantik berücksichtigen (Prinzip der thematischen Hierarchie) und sogar rein semantischer Natur sein können (Prinzip der Belebtheit).

Darüber hinaus wird zum anderen Evidenz für eine Beteiligung des posterioren Teils des Sulcus temporalis superior (pSTS) der linken Hemisphäre an der Verarbeitung von unmarkierter Transitivität gegeben. Unabhängig von der Wortstellung zeigte sich in dieser Region immer dann eine Aktivierungszunahme, wenn zwei belebte Argumente im Experimentalsatz enthalten waren, so dass die Aktivierung auf die relationale Rolle der Belebtheit zurückzuführen ist. Dieses zweite experimentelle Ergebnis lässt sich in bisherige neuroanatomische Daten einordnen, die bei Widersprüchen zwischen grammatischen Funktionen und thematischer Hierarchie ebenfalls eine erhöhte Aktivierung in dieser Region gefunden haben. Offensichtlich kann der pSTS funktional mit einer Interaktion zwischen syntaktischer und semantischer Information assoziiert werden, wobei die Belebtheit der Argumente einen wesentlichen Einfluss auf ihre Relation hat.

Insgesamt liefern die vorliegenden neuroanatomischen Daten eindeutige Beweise für den Einfluss des semantischen Merkmals Belebtheit beim Satzverstehen. Dabei wird eine erste klare Evidenz für den Einfluss dieses nicht-syntaktischen Parameters auf ein bislang ausschließlich mit syntaktischer Verarbeitung assoziiertes kortikales Areal gegeben. Neben der Untersuchung spezifischer linguistischer Fragestellungen bietet eine solche empirische Herangehensweise Möglichkeiten für die Entwicklung und Überprüfung von Sprachverarbeitungsmodellen auf der Basis behavioraler, neurophysiologischer und neuroanatomischer Daten.