Pronominal reference in sentences about persons or things investigated by temporal and spatial neuroimaging

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**PRONOMINAL REFERENCE IN SENTENCES
ABOUT PERSONS OR THINGS**

investigated by temporal and spatial neuroimaging

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**PRONOMINAL REFERENCE IN SENTENCES
ABOUT PERSONS OR THINGS**

investigated by temporal and spatial neuroimaging

PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit Maastricht,
op gezag van de Rector Magnificus,
Prof. mr. G.P.M.F. Mols
volgens het besluit van het College van Decanen,
in het openbaar te verdedigen
op donderdag 30 juni 2005 om 12.00 uur
door

Anke Hammer

geboren op 8 oktober 1976 te Burg, Duitsland

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Meiner Familie

Merseburger Zaubersprüche

Zeilengetreue Abschrift

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Übersetzung (von Wolfgang Beck)

Einst saßen Idisi, saßen auf den Kriegerscharen. Einige
fesselten einen Gefangenen, einige hemmten die Heere, einige
zertrennten scharfe Fesseln. Entspringe den
Fesseln, entfahre den Feinden! H.
Phol und Wodan begaben sich in den Wald. Dort
wurde dem Fohlen Balders der Fuß eingerenkt.
Da besangen ihn Sinhtgunt und Sunna, ihre Schwester.
Da besangen ihn Frija und Volla, ihre Schwester. Da
besang ihn Wodan, so wie er es gut verstand:
Wenn Knochenrenkung, wenn Blutrenkung, wenn Gelenk-
renkung: Knochen zu Knochen, Blut zu Blut,
Glied zu Glied! So seien sie zusammengefügt!

Im 10. Jahrhundert schrieb ein Mönch die Merseburger Zaubersprüche in althochdeutscher Sprache wahrscheinlich aus dem 8. Jahrhundert auf das leere Vorsatzblatt einer Messhandschrift. Diese Zeilen wurden erst 1841 von Georg Waitz entdeckt. Er verzichtete auf eine Veröffentlichung und überließ sie den Gebrüdern Grimm zur Bearbeitung. Jacob Grimm wählte diese dann zum Thema seines Antrittsvortrag vor der Berliner Akademie am 3. Februar 1842. Die Merseburger Zaubersprüche erhielten ihren Namen nach dem Fundort. Sie werden als Handschrift (Hs) 136 in der Bibliothek des Domstifts Merseburg verwahrt.

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Introduction

The purpose of this document is to provide a comprehensive overview of the project's objectives, scope, and deliverables. It serves as a reference for all stakeholders involved in the project, ensuring that everyone is aligned on the goals and expectations. The document is structured to provide a clear and concise summary of the project's key elements, including the project's purpose, scope, and deliverables.

The project is designed to address the following key areas:

- Project Purpose and Objectives

- Project Scope and Deliverables

- Project Timeline and Milestones

- Project Risks and Mitigation Strategies

- Project Communication and Reporting

- Project Budget and Resource Allocation

- Project Evaluation and Feedback

- Project Conclusion and Next Steps

- Project Appendix and Supporting Documents

- Project Glossary and Definitions

- Project Index and Table of Contents

- Project Acknowledgments and Credits

- Project Contact Information and Support

Reading is one of our daily businesses. We read books for pleasure, newspapers for information, emails for communication and so on. Among many things, in order to understand a text, we have to integrate the meaning and the syntactic relations among words. Usually we are not aware of the details of this cognitive task because it goes so well, mostly automatic, especially when there is coherence in terms of syntactic and semantic information. However, what makes a text coherent?

Text coherence can be studied in many ways. One would be, and this is the focus of this thesis, to consider the way personal pronouns are processed. Pronouns are linguistic devices that allow a speaker to refer to an earlier mentioned person or thing. Consider the sentence: "The woman is happy because she fell in love." It is easy to tell that "she" refers back to the earlier mentioned woman. This phenomenon, where one item in a sentence refers back to an element mentioned earlier in the sentences, is also labeled as establishing co-reference, as in the case of pronouns. This process requires working memory demands on the comprehending system because earlier mentioned items have to be reactivated during a possible searching process for an appropriate antecedent. However, in order to establish one candidate as the target reference, pronouns must be matched to the antecedent conceptually (semantically) and syntactically (gender). In the German language, a woman ('die Frau') for example has a female biological gender with a corresponding feminine syntactic gender. However, a jacket ('die Jacke') has just a feminine syntactic gender with no semantic reflex.

During processing a sentence with an anaphoric expression the reader has to go through at least three different steps: (1) a conceptual/semantic match between pronoun and its antecedent, (2) a syntactic match between pronoun and antecedent in terms of number/gender and/or case marking, and (3) an activation of the discourse representation in working memory in order to make the connection between the pronoun and its antecedent, which occurred earlier in time in discourse.

1.1 Models of sentence processing

There are two main classes of models on sentence processing to be differentiated. They agree that different sub-processes underlie the comprehension process. However, they differ in their characterization of the processes involved and the time course of the use of certain sorts of information (Hagoort, Brown & Osterhout, 1999; Frauenfelder & Tyler, 1987). One class of these models are so called serial or syntax-first models (i.e. Frazier & Fodor, 1987; Ferreira &

Clifton, 1988), which claim that the parser initially builds up a syntactic structure independent of semantic information. Within these models the syntactic component is explicitly restricted to the domain of syntactic information. Non-syntactic information does not influence the analysis of the sentence at that early stage. Semantic and pragmatic information are represented in a different component and are used at a later stage. Thus, these models assume that syntactic and semantic processes are supported by different components within the comprehension system, and these may be implemented by distinct brain regions at the neuronal level. The second class of models, so called interactive models, assume that syntactic and semantic information interact at any time during parsing (e.g. Marslen-Wilson & Tyler, 1980; Trueswell & Tanenhaus, 1994). In these models, all (available) sources immediately affect the parsing process without appealing a separate level of syntactic representation. Syntactic, lexical, and semantic/conceptual information are used interactively and continuously. For a recent debate concerning these controversial assumptions on a neural base, see Friederici (2002) versus Hagoort (2003).

1.1.1 A psycholinguistic model of pronoun processing

A major interest of psycholinguistic research is to find out how words, for example a pronoun and its potential antecedent are combined to form a coherent sentence. The pronoun has to be linked to a possible antecedent in terms of syntax and/or semantics – and this process is called co-reference. Garrod and Sanford (1994) presented a model with two stages for pronoun interpretation (see also Garrod & Terras (2000) for a recent discussion about discourse role resolution) with (1) a low level automatic process associated with establishing a link between anaphor and a previous expression (referred to as bonding), and (2) a stage, which is testing and resolving this link (referred to as integration). The bonding process could rely on a syntactic feature, i.e. the syntactic gender agreement of pronoun and antecedent. The integration process is responsible for evaluating the established link, i.e. by weighting syntactic and semantic information. Garrod and Sanford pointed out that the integration of the pronoun would come about through an interaction between the syntactic (gender) and semantic information of the pronoun and the focus state of the prior discourse representation. The term “focus” means that certain elements are more prominent in a discourse than others. If this is the case, the comprehension system makes an early commitment to the full interpretation of the pronoun. When either one of these conditions does not hold, commitment is delayed until further information has been encountered. In other words, during a first step the comprehension system loosely links the pronoun to a potential antecedent by a fast and

automatic process (bonding). This link is evaluated a little later in order to avoid errors in comprehension. If this evaluation process (resolution) reveals that the bonding was right in terms of semantic and syntactic information, the comprehension system confirms the establishment of co-reference between pronoun and antecedent. The evaluation process may be speeded up by the congruency of three information types: semantic, syntactic and focus information. This model is substantiated by the following reading experiment: Garrod, Freudenthal, and Boyle (1994) presented sentences containing contextually congruent or incongruent verbs while eye-movements were monitored in order to examine how early the inconsistency would be detected. Example material would be:

Dangerous Incident in the Pool

Elizabeth (1)/Alexander (2) was an inexperienced swimmer and wouldn't have gone in if the male lifeguard (3) hadn't been standing by the pool. But as soon as she/he got out of her/his depth she/he started to panic and wave her/his hands about in a frenzy.

(I) Within seconds she (1) sank/*jumped into the pool.

(II) Within seconds he (2 or 3) sank/jumped into the pool.

The authors observed elongated first pass fixations for incongruent compared to congruent verbs. This incongruence effect was found within the first 100 ms on the verb. However, it only occurred when the sentences contained pronouns that referred unambiguously to the focused subject of the sentence (as in I). Garrod and colleagues did not test what would happen if the bonding process were interrupted by an explicit incongruence of pronoun and antecedent.

Garnham, Oakhill, Ehrlich, and Carreiras (1995, experiment 1) tested whether a mere syntactic cue could affect the interpretation of a pronoun. The authors compared the effects of gender cueing in Spanish and in French about persons (biological/conceptual gender) and about things (syntactic gender) by measuring reading times and comprehension. An example sentence for persons that involves biological gender cueing was '*Rosaline* arrested Paul because he was stealing a car.' In this sentence type, the pronoun can be referred to one of the persons by its biological gender alone because the two persons differ in gender. In contrast, in the sentence '*Peter* arrested Paul because he was stealing a car,' the pronoun integration requires more inferential processing because it cannot be solved by gender information alone. Similar sentences were also created for things, which by necessity involve syntactic gender cueing – but no biological gender cueing. Garnham et al. (1995) did observe two gender-cueing effects: (1) Reading times were shorter in the cued condition compared to the non-

cued conditions for things and persons. While this gender-cueing effect was attributed to 'superficial' syntactic encoding of pronouns in sentences referring to things, the authors viewed it as being either superficial or semantically driven in the sentences about persons. (2) Interestingly, a stronger gender-cueing effect for sentences about persons compared to things was found for question answering times after sentence endings. The authors interpreted this effect as a change in information processing over time: to establish co-reference the semantic information (biological gender cue) becomes more relevant after sentence completion than the syntactic information (syntactic gender cue). This means that besides the question about what kind of information (syntactic and/or semantic) is accessed during pronoun integration there is the question about the time-course of establishing the co-reference during discourse comprehension using different types of information.

Other psycholinguistic studies also have shown the involvement of conceptual/semantic and syntactic information to establish the link between a possible antecedent and a pronoun (Rigalleau & Caplan, 2000). Others suggested that it is either conceptual/semantic information (Gernsbacher, 1991), or syntactic information, i.e. more surface related processing (Gordon & Hendrick, 1998) for establishing the co-reference.

Taken together, behavioral data showed a complex pattern that is not yet consistent. One reason for the variety of findings could be that eye-movements and reaction times have a limited temporal resolution concerning on-line measuring of cognitive processes. The model of pronoun processing proposed by Garrod and Sanford (1994) belongs to the class of syntax first model. Methods with higher temporal resolution may be better suited to validate or reject the given assumptions on pronoun resolution.

1. 2 ERP studies on pronoun processing

Event-related Potentials (ERPs) are minute voltage fluctuations of electrical activity produced by neurons in the brain that are recorded from various points on the scalp during the processing of cognitive tasks (see Münte, Urbach, Düzel & Kutas, 2000; Rugg & Coles, 1995; for language see Kutas, Federmeier, Coulson, King & Münte, 2000).

Previous ERP-studies have led to the identification of several components involved in semantic and syntactic processing. In a series of pioneering studies, Kutas and Hillyard (1980, 1983) found that semantic anomalies elicit a large negative component with a peak around 400 ms with a right centro-parietal maximum subsequent to the onset of the anomalous word,

the so-called N400 component. This N400 has been shown to be sensitive to semantic integration (Kutas & van Petten, 1994; Kutas & King, 1995), as well as to discourse integration (St. George, Kutas, Martinez & Sereno, 1999; Van Berkum, Hagoort & Brown, 1999; Frisch & Schlesewsky, 2001). Another important finding is that the amplitude and the latency of the N400 component depend on word-class. There are two word-classes to differentiate: open class or content words (such as nouns, verbs, adjectives or most adverbs) and closed class or function words (such as pronouns, determiners, conjunctions or prepositions). For example, Münte, Wierenga, Weyerts, Szentkuti, Matzke, and Johannes (2001, first experiment) compared these two word-classes with a word-list experiment. In this experiment, the N400 component was considerably smaller for closed-class words. This finding is in line with earlier studies (Kutas & Hillyard, 1983; Van Petten & Kutas, 1991; for a review see Kutas & van Petten, 1994). With respect to the processing of syntactic information an early left anterior negativity (LAN) and a late centro-parietal positivity (P600/SPS, syntactic positive shift) have been identified. The LAN has been observed to follow syntactic violations such as phrase structure errors (Friederici, Steinhauer, Mecklinger & Meyer, 1998; Münte, Heinze & Mangun, 1993; Neville, Nicol, Barss, Forster & Garret, 1991) and working memory demands (Münte, Schiltz & Kutas, 1998b; Streb, Rösler & Hennighausen, 1999). The P600 has been observed in response to syntactic violations (Osterhout, Holcomb & Swinney, 1994; Osterhout & Holcomb, 1992; Friederici, Steinhauer & Frisch, 1999; for a review see Hagoort, Brown & Osterhout, 1999) or, more generally, in situations requiring the reanalysis of the sentence (Osterhout et al., 1994; Friederici and Mecklinger, 1996; Münte, Heinze, Matzke, Wierenga & Johannes, 1998a). The P600 typically has a peak-latency around 500-600 ms after the critical word and a duration of several hundred milliseconds (Osterhout & Holcomb, 1992; Hagoort et al., 1999).

1.2.1 Syntactic co-reference

Osterhout and Mobley (1995) focused on the processing of violations in a sentence. In a first experiment requiring the judgment of sentence acceptability two types of violations were presented.

- (1) 'The hungry guest helped themselves/himself to the food.'
(Reflexive-antecedent number violation),
- (2) 'The successful woman congratulated herself/himself on the promotion.'
(Reflexive-antecedent gender violation).

The authors stated that if violations in these two cases were purely syntactic, a P600 should be expected. In contrast, if the sentences involve semantic violation, an N400 was expected. Violations of both number and gender of the reflexive pronoun elicited a P600-like component, but no N400. This result was interpreted as indicating a syntactic integration of the reflexive pronoun without a semantic reflex. Furthermore, the experiment revealed exact information about the time course of establishing co-reference. Following Osterhout and Mobley the process starts at about 500 ms after onset of the reflexive pronoun.

1.2.2 Semantic co-reference

King and Kutas (1997, see also Kutas et al., 2000) examined the response to pronouns that refer to a stereotypically male or female antecedent. The subject noun in the experimental sentence was an occupational title that was more or less likely to be filled by a person of female or male gender, i.e. 'The engineer redesigned the circuit because he/she had detected a flaw.' Readers appear to treat the female pronoun as mismatching because the probability of female engineers is small in reality. The ERPs elicited by such a non-stereotypical pronouns showed a large anterior negativity after about 200 ms and was related by the authors to working memory and/or discourse analyses. Alternatively, however, this effect could be interpreted as result of a syntactic violation. The 'engineer' was analyzed as masculine and as soon as the system processes the pronoun 'she', it discovers a syntactic mismatch. Another finding in this study was that mismatching pronouns elicited a larger N400 component. This effect could indicate an involvement of semantic and/or discourse processing of words during the integration of the pronoun into the sentence. However, please note that in a related study by Osterhout, Bersick, and McLaughlin (1997) reflexive pronouns that mismatched the gender of occupational stereotypes elicited a P600 component, indicating no N400 related semantic processes. One possible explanation for the difference in results between these two studies is that personal pronouns and reflexive pronouns are treated differently by the language system.

1.2.3 Syntactic and semantic co-reference:

In a recent study Schmitt, Lamers, and Münte (2002) examined the separate effects of biological and syntactic gender violation during pronoun processing. The study was conducted in German because the German language differentiates between biological gender (FEMALE/MALE) and syntactic gender (feminine, masculine, neuter), especially in the cases

of diminutives (das Bübchen_{MALE/neuter} [the little boy]). Subjects read sentences in which an antecedent (Bübchen_{MALE/neuter} [the little boy] or Bub_{MALE/masculine}) was introduced. Later a personal pronoun was presented which either agreed with both gender types, agreed with the antecedent in terms of syntactic gender only, or in terms of biological gender only, or violated both agreements. Example materials would be:

Diminutive as antecedent:

- (1) Das Bübchen_{MALE/neuter} will schlafen und darum schaltet er_{MALE/masculine} eine Lampe aus.
(biological gender agreement, syntactic gender violation)
- (2) Das Bübchen_{MALE/neuter} will schlafen und darum schaltet es_{neuter} eine Lampe aus.
(biological gender violation, syntactic gender agreement)
- (3) Das Bübchen_{MALE/neuter} will schlafen und darum schaltet sie_{FEMALE/feminine} eine Lampe aus.
(biological gender violation, syntactic gender violation)

Non-Diminutive as antecedent:

- (4) Der Bub_{MALE/masculine} will schlafen und darum schaltet er_{MALE/masculine} eine Lampe aus.
(biological gender agreement, syntactic gender agreement)
 - (5) Der Bub_{MALE/masculine} will schlafen und darum schaltet es_{neuter} eine Lampe aus.
(biological gender violation, syntactic gender violation)
 - (6) Der Bub_{MALE/masculine} will schlafen und darum schaltet sie_{FEMALE/feminine} eine Lampe aus.
(biological gender violation, syntactic gender violation)
- (Translation: The (little) boy wants to sleep and therefore he/she/it switches the light off.)

Overall, the results showed salient P600 effects for pronouns, with violations being more positive than non-violations. This indicated that the establishment of reference involves syntactic reanalysis. Furthermore, the authors observed N400 effects in sentences with non-diminutives (violations being more negative than non-violations), but not with diminutives. This showed that conceptual/semantic integration is involved during non-diminutive but not during diminutive pronoun processing; at least it could not be violated.

1.3 Anatomical locations of syntactic and semantic processing

At present, there are no MEG and fMRI studies reported, which investigated the process of building up co-reference during pronoun resolution. Therefore, we should concentrate on anatomical locations of syntactic and semantic processing during other language processes. Traditionally, Broca's and Wernicke's area have been considered based on specific impairments of patients with focal brain damage to be the most relevant brain structures for

language processing. This model has been modified and extended as a result of more precise neuroanatomical data and results from functional imaging studies (review: Brown, Hagoort & Kutas, 2000; Martin & Chao, 2001). In a PET study Indefrey, Hagoort, Herzog, Seitz, and Brown (2001) examined the cerebral blood flow (CBF) during syntactic processing in an experiment requiring the detection of grammatical errors in meaningless sentences. These sentences were compared with a control condition in which subjects had to read out unstructured strings of pseudo-words (no meaning) and function words. Indefrey and colleagues reported that an area of the left dorsolateral prefrontal cortex, adjacent to Broca's area activated by syntactic error detection, is involved in syntactic processing aspects. Whereas other prefrontal areas, i.e. right inferior frontal sulcus, and the left middle frontal gyrus, subserve general error detection processes. As an implication of their results on pseudo-word material the authors clarified the role of the left posterior prefrontal cortex in sentence-level processing, by showing that it is indeed syntax-related processing rather than a syntactically mediated semantic integration of word meanings that activates this cortical region.

A recent fMRI-study investigated the neuroanatomical correlates of semantic and syntactic information processing and possible interdependencies (Röder, Stock, Neville, Bien & Rösler, 2002). The researchers varied syntactic processing demands (easy vs. difficult to process word order sequences) and the meaningfulness of sentences (real- vs. pseudo-word sentences). The following material was presented auditorily:

- (1) Jetzt wird der Astronaut dem Forscher den Mond beschreiben. (*easy real-word*)
- (2) Jetzt wird den Mond dem Forscher der Astronaut beschreiben. (*difficult real-word*)
- (3) Jetzt wird der Pronasaut dem Schorfer den Rond bereuschen. (*easy pseudo-word*)
- (4) Jetzt wird den Rond dem Schorfer der Pronasaut bereuschen. (*difficult pseudo-word*)

Playing the sentences of these four conditions backward created the control condition ("backward speech"). For syntax Röder and colleagues reported that syntactic processing in comparison to backward speech resulted in an activation of the left perisylvian region, including the left inferior frontal cortex, and the superior and middle temporal gyri. Semantic in contrast to pseudo-word conditions elicited a stronger activation in both the anterior and the posterior perisylvian cortex. Syntactic difficulty had its strongest effect in the left inferior frontal region. This effect was stronger for real-word than pseudo-word conditions. Thus, semantic and syntactic manipulations interacted within inferior frontal cortex. The authors

suggested that brain areas show some processing specificity although both language aspects seem to be supported by overlapping brain systems.

Thus, there is no clear anatomic picture about the language system at present. Further research is needed to reveal a complete picture of a neural network for semantic and syntactic integration.

1.4 Verbal Working memory and pronoun processing

The use of anaphoric expressions taxes memory resources from a processing point of view because the system has to search for an appropriate antecedent between previously activated memory representations. Proper names are explicit, as they identify the antecedent directly. Thus, a proper name will not trigger any search processes. Pronouns on the other hand are far less explicit because the interpretation depends on e.g. the context, syntactical features, and search processes seem to be obligatory. This idea is substantiated by the fact that more explicit anaphoric expressions are resolved faster and linked with greater likelihood to the appropriate antecedents than less explicit anaphors (Dell, McKoon & Ratcliff, 1983; Garrod et al. 1994). Studies in which ERPs were recorded during pronoun processing obtained evidence that components of the ERP, particularly the so called left anterior negativity (LAN) and the N400, reflect such processes in working memory load (Kluender & Kutas, 1993). King and Kutas (1995) compared object and subject relative clauses. They found that object relative clauses, which impose extra load on working memory resources, evoke the LAN. This negativity followed the main verb, i.e. when the system had received all the information to resolve the syntactic structure. Streb and colleagues (1999) compared proper name anaphors and pronouns in parallel and nonparallel structure. A parallel structure means that a subject pronoun refers to a preceding subject noun, as in the sentence 'Peter besucht Julia in der Klinik. Dort hat er dem Arzt eine Frage gestellt.' The same holds for an object pronoun which is assigned to an object noun ('Peter besucht Julia in der Klinik. Dort hat die Schwester ihr eine Spritze gegeben.'). Resolving this structure is supposed to be easy because pronoun and noun have the same syntactic function. In contrast, a non-parallel structure, where the pronoun and the preceding antecedent have a different syntactic function, is more difficult to resolve. Therefore, this structure should impose extra load on the system. An example would be: 'Peter besucht Julia im Krankenhaus. Dort hat die Schwester ihm das Zimmer gezeigt.' or 'Peter besucht Julia im Krankenhaus. Dort hat sie dem Arzt den Besuch vorgestellt.' Streb and colleagues reported two ERP results: (1) Pronoun anaphors evoked a more pronounced

negativity than proper name anaphors between 270 and 420 ms latency range over the frontal cortex electrodes. Another relative negativity occurred between 510 and 600 ms over the parietal sites. (2) Anaphors in nonparallel positions compared to parallel positions were more negative over parietal sites. The authors hypothesized that these two effects are functionally related to discourse resolution including a search in working memory for the suitable antecedent.

Cooke and co-workers (2001) investigated the where of syntactic working memory with fMRI, by presenting sentences differing in grammatical structure (subject- vs. object-relative) and short-term memory demand (short vs. long antecedent gap). Material example would be:

1. [The strange man] in black who [] adored Sue was rather sinister in appearance.
(subject-relative, short antecedent gap)
2. [The cowboy] with the bright gold front tooth who [] rescued Julia was adventurous.
(subject relative, long antecedent gap)
3. [The flower girl] who Andy punched [] in the arm was five years old.
(object-relative, short antecedent gap)
4. [The mess boy] who Janet the very popular hairdresser grabbed [] was extremely hairy.
(object-relative, long antecedent gap)

The '[]' illustrates the appending noun and the antecedent gap. Subjects were asked to consider whether a male or a female performed the action described in the sentence. There were two main results. First, the right posterior superior temporal cortex showed an activation during processing of long distance antecedent-gap without any grammatical influence in comparison to a pseudofont baseline. This result was interpreted as showing that this area supports passive short-term memory during sentence comprehension. Second, the left inferior frontal cortex was associated with sentences that featured both an object-relative clause and a long antecedent-gap in comparison to the baseline. This suggests that this region supports the cognitive resources required to maintain long-distance syntactic dependencies during comprehension of grammatically complex sentences. Fiebach, Schlesewsky, and Friederici (2001) found comparable results for German short and long wh-questions differing in their grammatical function (subject vs. object wh-question).

1.5 Conclusion

Psycholinguistic studies (Garrod et al., 1994; Garnham et al., 1995) and ERP-studies showed the involvement of syntactic and semantic information for establishing co-reference between a pronoun and a suitable antecedent. Furthermore, electrophysiological studies showed that the semantic integration starts at about 300 ms (King & Kutas, 1997; Schmitt et al., 2002) and syntactic integration at about 400 ms (Osterhout & Mobley, 1995; Schmitt et al., 2002). Neuroimaging studies investigated syntactic processing with either detection of grammatical errors in meaningless sentences finding an activated area in the left dorsolateral prefrontal cortex, adjacent to Broca's area (Indefrey et al., 2001), or with varying syntactic processing demands finding an activation of the left perisylvian region, including the left inferior frontal cortex, and the superior and middle temporal gyri (Röder et al., 2002). Semantic processing elicited a stronger activation in both the anterior and the posterior perisylvian cortex.

Working memory demands were measured by varying the difficulty of the sentence structure and comparing full noun anaphors and pronouns (Streb et al., 1999). Parallel structures are supposed to be easier to resolve than nonparallel structures, and therefore demand extra processing. This extra processing (search in working memory) becomes manifested over parietal scalps as a negativity sharing features of an N400 component. Pronouns compared to full name anaphors revealed a more pronounced negativity of left frontal sites, being similar to a LAN and another N400-like effect. Anatomically the right posterior superior temporal cortex is suggested to be involved in processing of long distance compared to short distance antecedent-gap without any grammatical influence (Cooke et al., 2001). Possibly the left inferior frontal cortex supports cognitive resources required to maintain long-distance syntactic dependencies during comprehension of grammatically complex sentences, as has been suggested by Cooke et al. (2001).

1.6 Research aims

The present thesis addresses the issue of pronoun processing with a multi-method approach by applying three different methods with on one hand high temporal (i.e. ERP and ERF) and on the other high spatial resolution (i.e. fMRI) enabling us to zoom into two important domains of pronoun processing from a cognitive point of view, viz. the temporal (when) and the spatial (where). Furthermore, comparable materials across experiments were used to

investigate the issues of syntactic and semantic gender information integration and information integration in combination with verbal working memory processes during pronoun resolution. This enables us to present a coherent framework between studies for pronoun resolution investigating the when and where of neurocognitive processes in focus.

The research aims in detail:

Chapter 2 scrutinizes the interaction of conceptual/semantic (N400) and syntactic (P600) gender agreement during pronoun processing between an antecedent and a pronoun in sentences about persons or things in German using ERP.

Chapter 3 investigates the localization of neural generators of event-related field (ERF) components for conceptual/semantic and syntactic processes by means of distributed source analyses of MEG data.

Chapter 4 considers the localization of cortical areas and networks of semantic and syntactic processes with fMRI, and investigates a neural network for conceptual/semantic and syntactic integration.

Chapter 5 inspects the interaction of verbal working memory with conceptual/semantic and syntactic gender information processing during pronoun resolution using ERP.

Chapter 6 examines the localization of cortical areas of verbal working memory and possible interactions with conceptual/semantic and syntactic gender information processing during pronoun resolution using fMRI.

Pronominal reference in sentences about persons or things: An electrophysiological approach

Abstract

German pronouns (*er*_{MALE/masculine}, *sie*_{FEMALE/feminine}) that refer to a person are determined by the biological gender (MALE/FEMALE) and/or syntactic gender (masculine/feminine) of the person. Pronouns (*er*_{masculine}, *sie*_{feminine}) that refer to a thing are determined by the syntactic gender of this thing (Garten (garden)_{masculine}, Tasche (hand-bag)_{feminine}). The study aimed to investigate whether semantic integration, syntactic integration, or both are involved in establishing co-reference between pronoun and subject/antecedent in sentences. Here we focused on two event-related potential components: the SPS/P600, related to syntactic violation and reanalysis, and the N400 component, related to semantic integration problems. In one condition a person was introduced as antecedent and later referred to by a pronoun, which either agreed in biological/syntactic gender or not (biological/syntactic gender violation). In a second condition, a thing was introduced as antecedent and the corresponding pronoun either agreed in syntactic gender or not (syntactic gender violation). Results at critical pronouns showed a P600 effect for incongruent compared to congruent pronouns in both conditions with a centro-parietal maximum. This effect was larger for the person compared to the thing condition. We interpreted this finding as reflecting a syntactic integration process that can be influenced by conceptual/semantic and syntactic information of the antecedent type. Furthermore, at the word following the pronoun, we observed an N400 for the thing but not for the person condition. We suggest, supported by the results of a control experiment that this effect reflects continuous integration processes for things, whereas for persons the integration seems to be finished at pronoun position.

This chapter corresponds to:

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2.1 Introduction

The phenomenon of establishing co-reference with one item in a sentence, for example a pronoun referring back to an element mentioned earlier in the sentence is a central topic in attempts to understand language comprehension. The question about the underlying cognitive and neural mechanism of the co-reference, as well as the question what kind of information is accessed during comprehension of anaphoric expression have attracted the interest of linguists, psycholinguists and neuroscientists for quite some time and is still a matter of debate (Hankamer & Sag, 1976; Carreiras, Garnham, Oakhill & Cain, 1996; Osterhout et al., 1997; Gordon & Hendrick, 1998; Schmitt et al., 2002; Swaab, Camblin & Gordon, 2004). In this study we focus on pronominal reference as exemplified by the sentence *'The woman is happy because she is in love.'* or, as in the German sentence *'Die Blume ist schön, weil sie viel Sonne hatte. (The flower is beautiful because it ('she') had a lot of sunlight.)'* Reading these sentences the comprehender knows that *she* refers back to the *noun*. But how does he or she know this? Some psycholinguistic studies have shown the involvement of conceptual/semantic information (Gernsbacher, 1991) to establish the link, others have suggested that it involves syntactic information, i.e. more surface related processing (Gordon & Hendrick, 1998), or both (Garnham et al., 1995).

Garrod and Sanford (1994) presented a model with two stages for pronoun interpretation (see also Garrod & Terras, 2000) with (1) a bonding or immediate recovery stage, which is an automatic, more syntax-related process associated with establishing a link between anaphor and a previous expression, and (2) a resolution or immediate integration stage, which is testing and resolving this link. The integration is responsible for evaluating the established link, i.e. by weighting syntactic and semantic discourse information. In case of congruency, the integration process finishes with a so-called commitment. In case of incongruency, the integration process fails or is delayed.

We made use of event related potentials (ERPs) to further investigate pronoun processing. ERPs are minute voltage fluctuations of electrical activity produced by neurons in the brain that are recorded from various points on the scalp during the processing of cognitive tasks (Rugg & Coles, 1995; for language see Kutas, Federmeier, Coulson, King & Münte, 2000). Their high temporal resolution can be used to zoom into temporal aspects of establishing co-reference. Specific ERP components (i.e. the N400 and the P600) can be interpreted as showing semantic and/or syntactic processing.

Previous ERP studies on pronoun processing reported a variety of findings. For example, Osterhout and Mobley (1995) compared the ERPs to personal pronouns that either matched or mismatched the subject noun in biological gender as in 'The aunt heard that she/he had won the lottery.' They found that the mismatching pronouns elicited a P600 for participants judging such sentences as unacceptable. According to the authors, this P600 effect indicated syntactic integration. For participants who found such sentences acceptable, the ERPs to the mismatching trials included a larger negativity compared to matching trials, beginning at approximately 200 ms after pronoun onset. This negativity was interpreted as a consequence of adding new elements to the existing representation in order to make sense of the mismatching pronoun sentence.

Osterhout and colleagues (1997) investigated reflexive pronouns that referred to (i) definitionally or (ii) stereotypically male or female antecedents. One example would be: (i) The man prepared himself/herself for the interview. (ii) The doctor prepared himself/herself for the operation. Overall, the results showed that ERPs to gender incongruent pronouns were more positive than to congruent pronouns. Moreover, violations of gender definitions were more positive than violations of gender stereotypes. The authors concluded that ERPs are sensitive to violations of gender based on occupational stereotypes and that the observed ERP response is similar to the P600 elicited by syntactic anomalies (as shown by Osterhout & Holcomb, 1992; Hagoort et al., 1993; for a review see Hagoort et al., 1999). The P600 has also been observed in situations requiring the reanalysis of the sentence (Friederici & Mecklinger, 1996; Münte et al., 1998a).

King and Kutas (1997; see also Kutas et al., 2000) examined the response to pronouns that refer to a stereotypically male or female antecedent noun. The subject noun in the experimental sentence was an occupational title that was more or less likely to be filled by a person of female or male gender, i.e. 'The engineer redesigned the circuit because he/she had detected a flaw.' As one might expect, the paucity of female engineers in reality renders the version of this sentence with 'she' odd at first glance. Readers appear to treat the female pronoun as mismatching. One of the major findings of this study was that mismatching pronouns elicited a larger N400 component compared to matching pronouns. This N400 has been shown to be sensitive to semantic integration (Kutas & Hillyard, 1980, 1983; Kutas & van Petten, 1994), as well as to discourse integration (St George et al., 1999; van Berkum et al., 1999). The observed effect therefore indicates an involvement of semantic (world knowledge of stereotypes) and/or discourse processing of words during the integration of the pronoun into the sentence.

The results by Osterhout and colleagues (1995, or 1997) are on a first glance contrary to the results presented by King & Kutas (1997). However, a direct comparison is difficult due to the difference in design and material. For example, a reflexive pronoun has to be bound in its governing category, whereas a non-reflexive pronoun has to be free. Furthermore, reflexive pronouns, once processed, can only be syntactically correct or incorrect in the given sentence context, whereas personal pronouns offer more degrees of freedom in the interpretation. For example, in case of a mismatch, the parser may leave the sentence level and search within the discourse level for an appropriate antecedent, indexed by the negativity reported by Osterhout & Mobley (1995). In addition, the observed P600 difference in the Osterhout et al. (1997) study could alternatively be interpreted as an effect of semantic knowledge about gender stereotypes affecting the syntactic process. Then, semantic processing seems to be involved in the resolution process shown by the P600 variation between stereotype gender violations and clear biological gender violation conditions.

In a recent study Schmitt et al. (2002) examined the separate effect of biological and syntactic gender violation during pronoun processing. The study was conducted in German because the German language differentiates between biological gender (FEMALE/MALE) and syntactic gender (feminine, masculine, neuter), especially in the cases of diminutives (das Bübchen_{MALE/neuter} [the little boy]). Subjects read sentences in which an antecedent (Bübchen_{MALE/neuter} [the little boy] or Bub_{MALE/masculine}) was introduced. Later a personal pronoun (er_{MALE/masculine}/es_{neuter}/sie_{FEMALE/feminine}) was presented which either agreed with the antecedent in terms of both gender types, in terms of syntactic gender only, or in terms of biological gender only, or violated both agreements. Overall, the results showed salient P600 effects for pronouns, with the violations being more positive than the non-violations. This indicated that the establishment of reference involves syntactic reanalysis. Furthermore, the authors observed N400 effects in sentences with non-diminutives (violations being more negative than non-violations), but not with diminutives. This showed that conceptual/semantic integration is involved during non-diminutive but not during diminutive pronoun processing; at least it could not be violated.

Taken together, the ERP pronoun studies so far did not reveal a clear pattern with regard to the question what kind of information is used for linking a pronoun to its antecedent. The observation of N400 or P600 as indexes for semantic and syntactic processing respectively seems to be dependent on the type of pronoun and the type of antecedent. In addition, the interpretation of the P600 should be broadened. It can be a pure syntactic marker, but it can also be manipulated by semantic information (Müntz et al., 1998a). Also, note that all these

studies focused the ERP analysis on the pronoun position. It is therefore open so far if and how the co-reference process proceeds after pronoun input, a point that will be addressed especially in the second experiment.

Condition	Sentence
P: Person as antecedent	
C. congruent	Die Frau _{FEMALE} ist beliebt, weil sie _{FEMALE/feminine} schön ist.
I. incongruent	Die Frau _{FEMALE} ist beliebt, weil er _{MALE/masculine} schön ist.
T: Thing as antecedent	
C. congruent	Die Jacke _{feminine} ist warm, weil sie _{feminine} gefüttert ist.
I. incongruent	Die Jacke _{feminine} ist warm, weil er _{masculine} gefüttert ist.

Table 2.1 Example Materials for the experiment. Translation: P: The woman is popular because she/he is beautiful. T: The jacket is warm because she/he is lined. FEMALE = biological gender, masculine = syntactic gender masculine, feminine = syntactic gender feminine.

The aim of the current study is to further investigate the establishment of conceptual/semantic and syntactic gender agreement during pronoun processing. Specifically it was of interest, whether or not these processes differ for persons and things as antecedents. In contrast to English, German nouns referring to things have a syntactic gender, which is independent of any semantic information. Garden, for example, is masculine (der_{masculine} Garten_{masculine}), and flower is feminine (die_{feminine} Blume_{feminine}), while neither of these things are male or female. We assume to tap into unambiguous syntactic processing in this condition, reflected by a P600. Similar to English, a German noun referring to a person has a gender that is determined by the biological/conceptual gender. A woman, for example, has a female biological gender and a feminine syntactic gender (die_{feminine} Frau_{FEMALE} [the woman]). Because the two gender types coincide in this case, it is unclear which information is used by the linguistic system to establish co-reference between the pronoun “sie (she)” and the noun “die Frau”. It could be semantic information, syntactic information or both. Based on previous ERP findings, we consider three possible types of outcomes. If only biological gender (conceptual/semantic information) plays a role for persons then we would expect an N400 ERP effect in violations of biological gender assignment (according to the results of King and Kutas, 1997). If biological and syntactic gender play a role, we would expect an N400/P600 complex for double violations (as was observed by Schmitt et al., 2002),

reflecting a more modular and independent semantic and syntactic processing.¹ Alternatively, one could expect a difference between the P600 amplitude in the person compared to the thing pronoun manipulation (as was observed in the stereotype vs. clear biological gender violations by Osterhout et al. (1997) indicating an interaction of semantic and syntactic processing within the P600 component).

German subjects read sentences in which an antecedent was either a person (P) or a thing (T). This antecedent was introduced in the first phrase. In the second phrase a pronoun was presented which referred back to the antecedent in the first phrase (congruent pronoun C) or which was incongruent (I) with the antecedent (examples are given in Table 2.1).

Die Frau ist beliebt, weil sie/er schön ist.
The woman is popular, because she/he is beautiful.

Figure 2.1 Grand average ERPs time locked to the onset of the critical pronoun in sentences with a person as the antecedent at a selected set of electrodes (negativity is up and each hash mark represents 200 ms of activity in this and in the following figures).

¹ In case of modularity this complex has to be identical to the sum of the separate components (Osterhout & Nicol, 1999). A complex could also show an interaction (in case the sum is not identical to both component effects in isolation).

2.2 Results

Comprehension Task

The correct performance in the comprehension task was 83 % indicating that the subjects had indeed read and processed the sentences. Mean reaction time was 1800 ms (SD 350).

Figure 2.2 Grand average ERPs time locked to the onset of the critical pronoun in sentences with a thing as the antecedent at a selected set of electrodes.

ERPs

The grand average ERPs, time-locked to the onset of the critical pronoun, are shown in Figure 2.1 for Person-antecedents, and in Figure 2.2 for Thing-antecedents conditions.

The critical words elicit the N1-P2 complex that is typical for visually presented material, followed by a late negativity. In both antecedent conditions incongruent compared to congruent pronouns are characterized by a more negative waveform in the range of 300 – 400 ms after pronoun onset, especially at parietal sites. From 400 ms after onset and extending well into the ERP to the next word, the ERP to the incongruent stimuli is more positive than that to the congruent pronouns. This P600 effect is larger for sentences with a person compared to a thing as an antecedent.

Source	df	F	P(GG)
Omnibus ANOVA (29 electrodes)			
Antecedent type (Person vs. Thing)	1, 15	0.08	.8
Pronoun type (Congruent vs. Incongruent)	1, 15	4.59	.048*
Antecedent type x Pronoun type	1, 15	3.81	.07
Antecedent type x Electrodes	28, 420	1.70	.2
Pronoun type x Electrodes	28, 420	1.92	.1
Antecedent type x Pronoun type x Electrodes	28, 420	1.02	.4
Person: Omnibus ANOVA (29 electrodes)			
Pronoun type (PC vs. PI)	1, 15	0.92	.35
Pronoun type x Electrodes	28, 240	2.26	.08
Thing: Omnibus ANOVA (29 electrodes)			
Pronoun type (TC vs. TI)	1, 15	7.92	.01*
Pronoun type x Electrodes	28, 240	1.08	.37

Table 2.2 Gender agreement effects: Mean ERP amplitude ANOVAs in the 300 – 400 ms Latency Range (Negativity). Note: PC = congruent Person, PI = incongruent Person, TC = congruent Thing, TI = incongruent Thing; * $p < 0.05$; ** $p < 0.01$. GG = Greenhouse Geisser corrected p -value for F tests with more than one degree of freedom.

Negativity

Results of the repeated measures ANOVAs on mean amplitudes for the 300 – 400 ms time-window are reported in Table 2.2. The omnibus ANOVA revealed a main effect of Pronoun type with ERPs to incongruent conditions being more negative than congruent conditions. The interaction of Antecedent type with Pronoun type showed a trend. These effects were

Figure 2.3 Mean amplitudes of difference waves (incongruent minus congruent) are demonstrated for the Negativity (time-window 300-400 ms) at the left and the P600 (time-window 400-700 ms) at the right.

traced back to the following effects in separate ANOVAs for each Antecedent type. For Thing-antecedents, the ANOVA including 29 electrodes showed a significant main effect of Pronoun type. For Person-antecedents, the analysis including 29 electrode sites revealed a trend for Pronoun type x Electrode interaction. The Pronoun type effects (Negativity: incongruent minus congruent) are plotted in Figure 2.3, left panel, separately for the two antecedent types.

P600

The omnibus ANOVA on mean amplitudes for the 400 – 700 ms time-window revealed no significant main effect for the Antecedent types (see Table 2.3). There was a significant main effect of Pronoun type with ERPs to incongruent pronouns being more positive than those to congruent ones. As visible in the ERP waves, and in Figure 2.3, right panel: the pronoun-type effect (incongruent – congruent) for Person-antecedent was much larger than for Thing-antecedents. This difference was statistically reliable, as indicated by the significant interaction of Antecedent type x Pronoun type.

End of sentence effects

Figure 2.4 shows the grand average ERPs, time-locked to the onset of the critical pronoun up to the end of the sentence for things (left panel) and persons as antecedents (right panel), respectively. In addition to the ERP-pattern described before, Figure 2.4 (left panel) shows a more negative waveform for the word after the pronoun ('gefüttert') in incongruent sentences as compared to congruent sentences. This negativity begins at approximately 1000 ms after the pronoun and lasts to 1300 ms (corresponding to 400 – 700 ms after word onset) with a right-parietal maximum. This pattern is not visible in sentences about persons (see Figure 2.4, right panel). There appears to be a small negativity with a more anterior distribution than the classical N400 (most obvious at electrode F4 and C4).

Figure 2.4 Grand average ERPs time locked to the onset of the critical pronoun lasting until the end of the sentence with a thing as the antecedent (left panel) and with a person as antecedent (right panel) at a selected set of electrodes. The first word starts at 0 s, the second word at 0.6 s, and the sentence final word at 1.2 s. The same scaling holds for Figure 5.

Source	df	F	P(GG)
Omnibus ANOVA (29 electrodes)			
Antecedent type (Person vs. Thing)	1, 15	0.12	.7
Pronoun type (Congruent vs. Incongruent)	1, 15	15.16	.001**
Antecedent type x Pronoun type	1, 15	9.79	.007*
Antecedent type x Electrodes	28, 420	1.28	.3
Pronoun type x Electrodes	28, 420	7.08	.0001**
Antecedent type x Pronoun type x Electrodes	28, 420	1.35	.2

Table 2.3 Gender agreement effects: Mean ERP amplitude ANOVAs in the 400 – 700 ms Latency Range (P600). Note: PC = congruent Person, PI = incongruent Person, TC = congruent Thing, TI = incongruent Thing; * $p < 0.05$; ** $p < 0.01$. GG = Greenhouse Geisser corrected p-value for F tests with more than one degree of freedom.

Source	df	F	P(GG)
Omnibus ANOVA (29 electrodes)			
Antecedent type (Person vs. Thing)	1, 15	1.75	.2
Pronoun type (Congruent vs. Incongruent)	1, 15	0.95	.3
Antecedent type x Pronoun type	1, 15	3.58	.08
Antecedent type x Electrodes	28, 420	2.10	.08
Pronoun type x Electrodes	28, 420	0.97	.4
Antecedent type x Pronoun type x Electrodes	28, 420	1.10	.4
Thing: Omnibus ANOVA (29 electrodes)			
Pronoun type (TC vs. TI)	1, 15	6.36	.02*
Pronoun type x Electrodes	28, 420	0.79	.7
Thing: Parietal ANOVA (P3, Pz, P4)			
Pronoun type (TC vs. TI)	1, 15	12.86	.003**
Pronoun type x Electrodes	2, 30	0.09	.9
Person: Omnibus ANOVA (29 electrodes)			
Pronoun type (PC vs. PI)	1, 15	1.03	.3
Pronoun type x Electrodes	28, 420	1.26	.3
Person: Parietal ANOVA (P3, Pz, P4)			
Pronoun type (PC vs. PI)	1, 15	0.31	.6
Pronoun type x Electrodes	2, 30	1.03	.4
Pronoun type x Electrodes	2, 30		

Table 2.4 Gender agreement effects: Mean ERP amplitude ANOVAs in the 1000 – 1300 ms Latency Range after onset of the critical pronoun (N400). Note: PC = congruent Person, PI = incongruent Person, TC = congruent Thing, TI = incongruent Thing; * $p < 0.05$; ** $p < 0.01$. GG = Greenhouse Geisser corrected p-value for F tests with more than one degree of freedom.

Table 2.4 revealed that our pronoun manipulation in an omnibus ANOVA crossing factors Antecedent-type, Pronoun-type, and Electrodes did not show significant effects in the specified time-window, but a trend. Separate analysis for Thing-sentences showed a significant main effect for Pronoun-type in an Omnibus ANOVA and in a Parietal ANOVA, indicating an N400 (400-700 ms) effect. Analysis for Person-sentences revealed no significant effects in this time-window, indicating that the violation did not affect the processing of the word after the pronoun in this condition. An additional ANOVA on right fronto-central sites (C4, F4) did not reveal a significant main effect for Congruency (Pc vs. Pi) for Person sentences $F(1,15) = 1.17, p < .3$.

Discussion 1

The aim of this experiment was to investigate the role of conceptual/semantic and syntactic information in the process of establishing co-reference between a pronoun and its antecedent. In German things have a clear syntactic gender. We therefore expected to tap into pure syntactic processing during the violation of the pronoun gender, which should be reflected by a P600. In contrast, the person antecedents within this experiment have an unambiguous biological gender, which coincides with syntactic gender. Thus, in the case of a person antecedent conceptual/semantic information (viz. the biological gender) and syntactic information might be used to establish co-reference. We found a more positive ERP for incongruent compared to congruent pronoun types. This P600 effect was larger for person than for thing-antecedent type sentences. If we take only the overall P600 pattern into account, these findings suggest that establishing co-reference might be a syntactic process in general. Moreover, the fact that the P600 was larger for persons compared to thing-antecedents shows that the syntactic process, in this case the reanalysis of the sentence, might interact with semantics if semantic knowledge is available. Besides, we found a small negativity at left parietal sites in the time window between 300 and 400 ms after pronoun onset. This observed negativity, however, did not resemble a standard N400 effect, which usually is more prominent over the right hemisphere and lasts longer (Kutas & Hillyard, 1983, Münte et al., 2001; for a review see Kutas & van Petten, 1994). Therefore, we can only speculate here about a possible explanation. Since we found this effect within the thing-condition - where we expected pure syntactic gender information processing - this negativity could be due to a search for an actor outside the sentence in case of an incongruent pronoun, i.e. leaving sentence level and search within the discourse model (from a cognitive point of view comparable to the anterior negative effect found by Van Berkum, Brown, Hagoort &

Zwitsersloot (2003) for discourse-referential ambiguity). Thus, it has to be considered that the pre-P600 negativity results could be interacting with the following P600. In other words, the P600 to Thing-pronouns might not really be smaller than that to Person-pronouns, rather it might be the larger negativity to Thing-pronouns that “pulls down” the subsequent P600 (i.e., this might be a component overlap issue rather than a pure P600 issue).

We also observed an unexpected N400 at the word following the pronoun. This N400 was significant for thing-antecedent types, and was absent for person-antecedent types. As a possible interpretation we suggest that this pattern reflects two types of processing: In the person case, the gender violation at pronoun position is so severe (syntactically and biologically bonding and resolution is signaling violation) that the reader/parser stops further attempts to integrate this mismatching pronoun immediately. Thus, no electrophysiological signs of integration attempts were found for the following word. In the thing case, the gender violation is purely syntactical and therefore the bonding process signals “violation”, but due to the lack of any semantic information, a resolution does not take place at pronoun position. The reader/parser is waiting for new incoming information to solve this incongruency. For example, the parser waits for (anticipates) a word that is related to any alternative antecedent in the discourse. But when the word matches the thing-antecedent in meaning (in our example: ‘gefüttert’), the comprehension system is unable to link the pronoun to any alternative antecedent. Therefore the integration process of the incongruent pronoun finally signals violation at word position after the pronoun indexed by the N400. To test this assumption, we conducted a second experiment that manipulated the word following the pronoun and added discourse information.

Experiment 2: Pronoun integration depending on context information

We performed this follow-up experiment for two reasons. First, we wanted to replicate the observed N400 pattern at the word following the pronoun for the thing-antecedent sentence types. In addition, we wanted to test our assumption that in case of pure syntactic gender violation as in our thing sentences, the system keeps on looking for a meaning in the sentence or alternatively within the discourse. We used thing-antecedents and corresponding pronoun violations that were identical to those used in the first experiment. A context was created by adding a sentence preceding the target sentence. This sentence always introduced a person as an additional antecedent, i.e. a potential alternative to the thing-antecedent. This person could either have the same syntactic gender as the thing in the second sentence (ambiguous; A) or

not. Therefore the person was either congruent (C) or incongruent (I) to the pronoun. In addition, the word following the pronoun could either refer in meaning to the thing or to the alternative discourse person, leading to 6 experimental conditions in total (Table 2.5).

Condition	Sentence
CT: Context Thing	
A. ambiguous	Die Frau _{FEMALE/feminine} steht im kalten Schnee. Die Jacke _{feminine} ist warm, weil sie _{FEMALE/feminine} gefüttert _{THING} ist.
C. congruent	Der Mann _{MALE/masculine} steht im kalten Schnee. Die Jacke _{feminine} ist warm, weil sie _{feminine} gefüttert _{THING} ist.
I. incongruent	Der Mann _{MALE/masculine} steht im kalten Schnee. Die Jacke _{feminine} ist warm, weil er _{MALE/masculine} gefüttert _{THING} ist.
CP: Context Person	
A. ambiguous	Die Frau _{FEMALE/feminine} steht im kalten Schnee. Die Jacke _{feminine} ist warm, weil sie _{FEMALE/feminine} friert _{PERSON} schnell.
C. congruent	Der Mann _{MALE/masculine} steht im kalten Schnee. Die Jacke _{feminine} ist warm, weil er _{MALE/masculine} friert _{PERSON} schnell.
I. incongruent	Der Mann _{MALE/masculine} steht im kalten Schnee. Die Jacke _{feminine} ist warm, weil sie _{feminine} friert _{PERSON} schnell.

Table 2.5 Example Materials for the follow-up experiment. Translation: The man/woman stands in the cold snow. The jacket is warm because she/he is lined/ freezes fast. FEMALE = biological gender female, MALE = biological gender male; masculine = syntactic gender masculine, feminine = syntactic gender feminine, THING = word refers to the thing in meaning; PERSON = word refers to the person in meaning.

In our example the word ‘gefüttert’ [lined] can only refer to the thing-antecedent ‘Jacke’ (context: thing; CT) within the same sentence, whereas the word ‘friert’ [freezes] can only refer to the person (context: person; CP) - to the alternative antecedent outside the sentence. The underlying rationale is the following. If the pronoun matches either the within- or outside-sentence antecedent (CTA and CPA), there is no violation between the word following the pronoun and antecedent, and the process of co-reference is finished at this word position (ERP baseline condition). In the case of a pronoun-thing antecedent violation (CTI), (i) the parser waits for new input related to either the within- or a controlled outside-sentence antecedent. (ii) The parser checks the match between the new word and pronoun, and (iii) between new word and within-sentence antecedent. (iv) In case of no-match, the parser looks for alternative antecedents – i.e. somewhere outside the sentence (experiment 1), or in the preceding sentence (experiment 2). Thus, the baseline conditions are those cases where the pronoun can refer back either to the thing-antecedent or the additional person-antecedent. Also, when the word following the pronoun refers back to the discourse antecedent, all words can be processed on-line without any problems. In contrast, an N400 is expected in two cases: a) if the pronoun does not match the thing-antecedent, AND the following word does not

match the discourse-antecedent (CTI) or b) if the following word does match the thing-antecedent and the pronoun, but does not match the discourse-antecedent in meaning (CTC).

Results Experiment 2

The grand averages ERPs, time-locked to the pronoun up to the end of the sentence for the thing-context (left panel, CT) and for the person-context (right panel, CP) are shown in Figure 2.5. Around 1000 ms after the pronoun (equivalent to 400 ms after word following the pronoun) all conditions revealed a deflection towards negativity lasting until 1300 ms with a right-parietal maximum. In this 1000 – 1300 ms time window this deflection was different within the thing context for pronoun types with CTI being more negative than CTC than CTA. This suggested a modulation of the N400 component. This N400 pattern is not visible when the meaning of the word following the pronoun refers to the person. However, there seems to be a trend towards a negativity with more anterior distribution for the person context. The statistical analysis for the N400 time window (1000-1300 ms) for the word following the pronoun is reported in Table 2.6. The omnibus repeated measures ANOVA revealed no significant main effects. A more specific parietal analysis resulted in a significant main effect for Pronoun-types indicating indeed a manipulation of the N400. Separate

Figure 2.5 Grand average ERPs time locked to the onset of the pronoun lasting until the end of the thing-context (CT) sentence (left panel) and the person-context (CP) sentence (right panel) at a selected set of electrodes.

planned comparison of Pronoun types for the Thing-Context within the specified time-window for electrode site P4 (the site that showed most clearly the N400 in experiment 1) revealed a significant difference between Pronoun-types. Additional planned pair-wise comparisons revealed significant differences between CTA and CTI (t_{15} ; one-tailed = 53.51, $p < .003$) and between CTA and CTC (t_{15} ; one-tailed = 22.04, $p < .04$). In contrast, there was no difference between Pronoun-types for the Person-

context conditions. These results indicate that there was an N400 effect for pronoun-types within the thing-context (see Figure 2.5, left panel), whereas this manipulation did not affect the word after the pronoun within the person-context (Figure 2.5, right panel). Because of a possible anterior negativity for the Person-context we performed an additional separate frontal ANOVA the Person-context which crossed the factors Pronoun type (3; ambiguous vs. congruent vs. incongruent) and 'Electrode sites' (2 levels, C4, F4). This analysis resulted in no main effect for the Person-Context; $F(2,30) = 0.55$; $p < .6$.

Source	df	F	P(GG)
Omnibus ANOVA (30 electrodes)			
Context (Person- vs. Thing-antecedent)	1, 15	0.05	.8
Pronoun (A vs. C vs. I)	2, 30	2.25	.1
Context x Pronoun	2, 30	0.56	.6
Context x Electrodes	29, 435	1.00	.4
Pronoun x Electrodes	58, 870	1.51	.2
Context x Pronoun x Electrodes	58, 870	0.94	.5
Parietal ANOVA (P3, Pz, P4)			
Context (Person- vs. Thing-antecedent)	1, 15	0.10	.8
Pronoun (A vs. C vs. I)	2, 30	5.10	.01*
Context x Pronoun	2, 30	0.20	.8
Context x Electrodes	2, 30	0.01	.9
Pronoun x Electrodes	4, 60	1.40	.3
Context x Pronoun x Electrodes	4, 60	2.23	.09
Single electrode (P4)			
Context (Person- vs. Thing-antecedent)	1, 15	0.17	.7
Pronoun (A vs. C vs. I)	2, 30	6.48	.006**
Context x Pronoun	2, 30	0.93	.4
Planned Comparison P4: Thing-Context			
Pronoun (A vs. C vs. I)	2, 30	4.13	.02*
Planned Comparison P4: Person-Context			
Pronoun (A vs. C vs. I)	2, 30	0.76	.8

Table 2.6 Mean ERP amplitude ANOVAs in the 1000 – 1300 ms Latency Range after onset of the pronoun (N400 at following word) for the second experiment. Note: A = ambiguous, C = congruent, I = incongruent; * $p < 0.05$; ** $p < 0.01$. GG = Greenhouse Geisser corrected p-value for F tests with more than one degree of freedom.

Discussion 2

The aim of the second experiment was to replicate the observed N400 at the word following the pronoun that has a syntactic gender violation with the within sentence thing-antecedent. In addition, to test our post hoc explanation for the effect, we systematically added out-of-sentence context and manipulated the word following the pronoun. As a replication of experiment 1, we observed a more negative effect on the word following the pronoun within

an incongruent sentence about things, but no effects for pronouns referring to a person out-of-the sentence. For the thing-context, the incongruent condition was more negative than the congruent condition (see Figure 2.5). This effect could be interpreted as an ongoing integration process in order to get the meaning of the pronoun correct. This revision might be characterized by a searching process for an alternative antecedent in the discourse. Therefore, the parser waits for new information, in order to solve this incongruity, i.e. expecting a relation to an alternative antecedent in the discourse. The N400 occurs if this process fails. It fails a) if the pronoun does not match the thing-antecedent, AND the following word does not match the discourse-antecedent in meaning (CTI), or b) if the following word does match in meaning with the thing-antecedent and the pronoun, but does not match with the discourse-antecedent in meaning (CTC). In contrast, in the person-case a revision does not take place at the word following the pronoun, indicating that the integration process for these pronouns seems to be finished right after pronoun processing due to a reliable declining of bonding/resolution of pronoun and person-antecedent.

2.3 General Discussion

We conducted two experiments to investigate the role of syntactic and semantic information in the establishment of pronoun resolution in sentence reading. In experiment 1, congruency was manipulated in sentences with either Persons or Things as antecedents. For incongruent sentences with person as well as thing-antecedents we found a clear P600 effect at pronoun position indicating an involvement of syntactic information and/or sentence reanalysis during pronoun processing. This P600 finding is in line with other ERP findings (Osterhout & Mobley, 1995; Osterhout et al., 1997, Schmitt et al., 2002).

The P600 was significantly stronger in sentences with a person than a thing as an antecedent. Granted the assumption that the size of the P600 effect reflects the effort of reanalyzing and/or syntactically repairing the sentence at pronoun position, this result indicates a larger effort to reanalyze and/or repair in sentences with persons (in which both types of gender are violated) compared to things (violation of syntactic information only). The observed difference in P600 effects might not just be an indicator for syntactic violations. Rather, it might be a response to reanalysis of the sentence as well, including both syntactic and semantic aspects (for a discussion see Münte et al., 1998a). Granted the assumption that the difference in size is related to a component-overlap of the pre-P600 negativity (i.e. which

“pulls down” the P600 to Thing-pronouns) as indicated in Discussion 1, this result could indicate that already at the pronoun position the comprehension system is prepared to search for a possible animate discourse antecedent, i.e. another person. This possibility is confirmed by the unexpected finding in experiment 1. We found an N400 effect in incongruent sentences about things at the word following the pronoun, indicating ongoing semantic integration/reanalysis. This N400, however, was only observed for sentences with a thing as within sentence antecedent, and not when this was a person.

In experiment 2 we replicated and investigated this finding further. We provided an additional discourse sentence with either a female or a male person as subject as an alternative antecedent preceding the thing-sentences of the first experiment. Furthermore we manipulated the word after the pronoun in such a way that it either belonged to the thing-antecedent (Thing-Context) or to the new person-antecedent (Person-Context) in the preceding discourse sentence. Thus, the pronoun in the Thing-sentence could either refer back ambiguously to the thing-antecedent or to the person-antecedent or congruently/incongruently to the thing-antecedent or finally congruently/incongruently to the person-antecedent. Our ERP data revealed a clear N400 effect on the word following the pronoun for the thing-context whenever there was a violation, but not in the person-context. The N400 has been shown to be sensitive to semantic integration (Kutas & van Petten, 1994). Thus, our N400 effect indicates that there was still an ongoing integration process on the word following the pronoun if it referred to the thing in meaning, but not if it referred to the person. Furthermore, based on the observed N400 effect size this integration can be differentiated depending on the given context. For example, the N400 was of medium size when the pronoun and the following word agreed with the within sentence antecedent, but when the following word did not fit in meaning to the discourse antecedent. Based on the type of violation in this condition, we suggest that this medium sized N400 does not reflect an integration problem within the sentence, but rather a violation of discourse processing. The N400 was large when the pronoun did not agree in gender with the within sentence antecedent and the following word did not agree in meaning with the discourse antecedent. The larger N400 indicates a sort of double violation, i.e. a failure of agreement within the sentence, and within the discourse. So far, we cannot say which of the agreement processes comes first, or has priority. It seems as if both – the within and between sentence integrations – take place as default. So, in case of no agreement the parser anticipates for a disjoint co-referential relation preferably to a person-antecedent because of the preference for pronouns to refer to persons. In order to anticipate incongruent thing-sentences the language system

expects a word with such a semantic content that the pronoun fits referring to the discourse-person. "Gefüttert" is not such a word and therefore there is a lexical integration problem of this word. For the person context there is no N400 for the word following the pronoun. In this case the comprehension system is not hampered in searching for an alternative antecedent after the pronoun because this word refers in meaning to the person-antecedent and a disjoint co-referential relation is established.

Taken together, the data of the two experiments show that at pronoun position violations in syntactic and in a combination of syntactic and biological gender violation are reflected in the P600. The larger P600 for person compared to thing antecedent types shows that the P600 is sensitive to the underlying semantic information of the antecedent (here, whether or not it has biological gender). The observed N400 on the word following the pronoun in case of thing but not person antecedent types within the same sentence indicates, for the first time that after violations of the pronoun the parser tries to integrate at later sentence positions, and it does so differently for each type of antecedent.

2.4 Methods

Experiment 1

Subjects

Twenty-one subjects volunteered for paid participation in the experiment. Five datasets could not be used due to too many artifacts or technical problems. The final population of subjects comprised sixteen native speakers of German, age range 20 to 30, mean age 24.6 years, 8 women. All subjects had normal or corrected-to-normal vision, were right-handed according to self-report and neurologically healthy.

Material

Two-hundred-forty sentences, 120 about persons and 120 about things were constructed. Each sentence had two clauses. The first clause in each sentence was the main clause, which described a state of a person or a thing. The person or the thing was the subject of the main clause, and formed the antecedent of the pronoun following later. Care was taken to guarantee equal word frequencies for persons and things using the CELEX-database (Baayen, Piepenbrock, & Gulikers, 1995). The second clause was a subordinate clause introduced by the conjunction *weil* (*because*). This conjunction was followed by the critical

word, a pronoun referring to the person or the thing. All sentences were then copied and the congruent pronoun was replaced by an incongruent pronoun (see Table 2.1 for examples). This resulted in a total of 480 sentences and in four conditions with 120 sentences per condition: (PC) A person as an antecedent with a congruent pronoun, (PI) a person with an incongruent pronoun and (TC) a thing as an antecedent with a congruent pronoun, (TI) a thing with an incongruent pronoun. The sentences were pseudo-randomized over four blocks, such that each condition appeared thirty times in each block, and that the sentences with the same subjects in the main clause were not in the same block.

In order to keep participants attentive, and to guarantee that they read the sentences, every 10 ± 5 sentences one of 48 comprehension questions was presented. These questions pertained to the immediately preceding set of 10 ± 5 sentences and required a yes/no response. Subjects had to press one out of two buttons for "yes" or "no". This task was independent of the pronoun manipulation.

The words were presented visually on a back projection screen at a distance of 100 cm. Critical words subtended 0.5 degrees of visual angle in height and 1.2 degrees in width.

Procedure

Participants were tested in a dimly lit sound-attenuating room. They were seated in a comfortable chair. Their instructions were to read the sentences carefully, and to answer the questions related to the sentences from time to time. They were free to blink between the sentences and while answering the questions, but were instructed to fixate on the screen, to be as relaxed as possible and to avoid all movement while reading the sentences.

A trial started with a fixation cross in the middle of the screen, presented for 2050 ms with a 300 ms inter-stimulus interval, and was followed by the word-by-word presentation of the sentence. Each word was presented for 350 ms with a 250 ms inter-stimulus interval. Sentence ending words were presented with a dot indicating the end of a sentence, followed by a blank screen for 850 ms.

Questions were presented on the screen for 4 s. One block lasted approximately 15 minutes. The entire experiment, including instructions, electrode application and removal took about 2.5 hours.

EEG recording and analysis

Electroencephalography (EEG) signals were registered with a digitization rate of 254 Hz and filtered with a band pass of DC to 50 Hz. Twenty-nine tin electrodes were applied according

to the 10/20 system (positions: Fz, Cz, Pz, Oz, Iz, Fp1/2, F3/4, F7/8, T7/8, C3/4, P3/4, O9/10, P7/P8, Fc1/2, Cp1/2, Po3/4, Po7/8). Bio-signals were recorded with a left mastoid reference, and were offline re-referenced to the mean of the activity at the two mastoids. Horizontal eye movements were recorded from an electrode behind the right lateral orbital ridge and referenced to an electrode at the left orbital ridge. Eye blinks and vertical movements were recorded from an electrode below the right orbital limb and referenced to the left mastoid. EEG and EOG signals were amplified using a 32-channel Synamps amplifier. All electrode impedances (EEG and EOG) were kept below 5 kOhm.

From the continuous signal epochs were created of 1006 ms starting 100 ms prior to pronoun onset. These epochs were monitored for artifacts, such as eye-movements, by an automated procedure. Trials including artifacts were rejected from further analysis. By averaging the remaining artifact-free epochs per condition the Event-related potentials (ERPs) were derived. The mean number of trials contributing to the average was 107 (PC and TC conditions) and 108 (PI and TI conditions). Waveforms were quantified by mean amplitude measures to assess N400 (time window 300 to 400 ms) and P600 (400 to 700 ms) components. Note that the N400 time window diverges from the standard N400 time window (usually between 300 and 500 ms) in order to avoid overlap with the P600 time window. These windows were derived from previous pronoun experiments of our group (Schmitt et al., 2002) and corroborated by visual inspection of the grand average ERPs. These measures were subjected to repeated measures analysis of variance that crossed the factors Antecedent type (2; person vs. thing), Pronoun type (2; congruent vs. incongruent) and 'Electrode sites' (29 levels). The Greenhouse-Geisser correction for inhomogeneity of covariance was applied whenever an evaluated effect had more than one degree of freedom in the numerator. Reported p-values are corrected. Additionally, we compared the mean amplitudes of conditions in the N400 time window by separate analyses for Pronoun type (PC vs. PI, and TC vs. TI). Finally ERPs were averaged for 2012 ms epochs with a 100-ms pre-stimulus interval in order to analyze the processing of the end of the sentence. These measures were subjected to repeated analysis of variance following the same logic as above and an additional analysis for the parietal line (P3, Pz, P4) in a time window from 1000 to 1300 ms (corresponding to a 400-700 ms time-window for the word after the pronoun).

Experiment 2

The second experiment followed the same procedure as the former experiment with regard to the timing of stimulus display, and EEG recording (despite one additional electrode – Fpz).

Subjects

Twenty subjects volunteered for paid participation in the second experiment. Four datasets were rejected due to too many artifacts. The final population of subjects consisted of sixteen native German speaker, age range 20 to 27, mean age 22.0 years, 11 women. All subjects had normal or corrected-to-normal vision, were right-handed according to self-report and neurologically healthy.

Material

Fifty congruent thing-sentences of the former experiment were selected. Additionally we created two types of discourse sentences with a person as a subject who had either the same gender as the thing (ambiguous pronoun resolution, CTA and CPA) or not (see Table 2.5 for example material). If context person and thing-antecedent had different gender, the pronoun 'he' could refer back to the man and the pronoun 'she' to the jacket in our example. Furthermore we replaced the word following the pronoun ('gefüttert' lined) with a word ('friert' freezes) that resolves the sentence in such a way that the second clause belongs to the person in the added context-sentence. At that point of sentence processing the re-reference of the pronoun is clear: either being congruent (CTC) or incongruent (CTI) to the thing ('Jacke and gefüttert' jacket and lined) or either congruent (CPC) or incongruent (CPI) to the person ('Mann/Frau and friert' man/woman and freezes). Thus, the material resulted finally in six different conditions. The material was distributed across two lists remaining 25 sentences per condition in one list, counterbalancing the thing-antecedent and the word following the pronoun. On a given list each thing-antecedent appeared three times with one person-context and two thing-context words following the pronoun or vice versa. Sentences on a list were pseudo-randomized over two blocks in such a way that the same thing-antecedents were kept apart as far as possible. We measured eight subjects per list. They were pooled again for later analyses.

Analyses

The time window for the mean amplitude analyses of the N400 was 1000-1300 ms after pronoun onset, as in experiment 1. The mean amplitude values were subjected to repeated measures analysis of variance that crossed the factors Context (2; Person- vs. Thing-Reference), Pronoun type (3; ambiguous vs. congruent vs. incongruent) and 'Electrode sites' (30 levels). Additionally, we compared the mean amplitudes of conditions in the N400 time

window by separate analysis for the parietal line (P3, Pz, P4), and by means of planned comparisons between conditions for the single electrode P4. P4 was singled out because of the observed maximum of the effect in experiment 1, and because of the expectation of a right centro-parietal hemispheric maximum for the N400 amplitude. Reported p-values are corrected via Greenhouse-Geisser correction for inhomogeneity of covariance.

Pronoun resolution in sentences about persons or things investigated by Magnetoencephalography

Abstract

The previous event-related potential (ERP) study revealed a clear pattern of pronoun resolution for person and thing antecedents in German. For incongruent sentences with person as well as thing-antecedents, we found a P600 effect at pronoun position indicating an involvement of syntactic information and/or sentence reanalysis during pronoun processing. The P600 was significantly larger in sentences with a person than a thing as antecedent. This observed difference in P600 effects was interpreted as a possible response to reanalysis of the sentence, including both syntactic and semantic aspects. We used magnetoencephalographic recordings to gain deeper insights into the spatial domain of this cognitive process. Statistical analysis did not reveal reliable differences for the event-related fields (ERF) between incongruent and congruent pronouns for both antecedent types. This result was discussed as demonstrating different outcomes for ERP and ERF data due to different characteristics of the two methods, i.e. measuring tangential vs. radial sources or widely distributed sources for higher cognitive processes.

3.1 Introduction

In order to gain further insights into the temporal and spatial domain of pronoun processing, magnetoencephalography (MEG) signals were acquired simultaneously with the EEG signals described in the first experiment. As mentioned in more detail before, in German a Person carries two types of gender information; namely biological/conceptual and corresponding syntactic gender information. In contrast, things are only characterized by (arbitrary) syntactic gender information. This characteristic of the German language enables the experimenter to systematically manipulate conceptual/biological and syntactic gender information during the process of pronoun processing. A pronoun, which refers back to a person may be re-referenced by conceptual and/or syntactic information, i.e. as exemplified by the sentence '*Die Frau_{FEMALE/feminine} ist beliebt, weil sie_{FEMALE/feminine}/*er_{MALE/masculine} schön ist.* [The woman is popular because she/*he is beautiful.]'. The '*' marks the incongruent pronoun. On the other hand, a pronoun, which refers back to a thing can solely be re-referenced by syntactic gender information, as in '*Die Jacke_{feminine} ist warm, weil sie_{FEMALE/feminine}/*er_{MALE/masculine} gefüttert ist.* [The jacket is warm because (it) she/*he is lined.]'. It was of interest whether semantic integration, syntactic integration, or both support the process of co-reference between a pronoun and a subject within sentences about either a person or a thing as an antecedent. For incongruent sentences with person as well as thing-antecedents, we found a clear P600 effect at pronoun position indicating an involvement of syntactic information and/or sentence reanalysis during pronoun processing. The P600 was significantly larger in sentences with a person than a thing as antecedent. This observed difference in P600 effects was interpreted as a possible response to reanalysis of the sentence, including both syntactic and semantic aspects.

For the MEG approach the same basic question arises: Do the processes of establishing co-reference between a pronoun and an antecedent differ for person or thing sentences? If so, are they detectable with MEG? Additionally to the ERP-experiment, an event-related fields (ERF) experiment may reveal better spatial information about the investigated processes.

Every current generates magnetic fields according to the right hand rule of physics. The very same principle is applied in the nervous system. Thus, MEG measures the intracellular currents of neurons in the brain giving direct information about the brain's activity, spontaneously or to a given event (Hämäläinen, Hari, Ilmoniemi, Knuutila & Lounasmaa, 1993; Papanicolaou, 1998). Here, as for ERPs, a large synchronously activated population of

neurons is needed to generate a measurable signal. Time locking the magnetic signal to an event and averaging several sequences reveals the ERF. MEG provides a better spatial resolution than ERPs because the magnetic permeability of biological tissues is practically the same as empty space. The temporal resolution is comparable to ERP.

Previous MEG studies on sentence processing focused mainly on the magnetoencephalographic counterparts to the left anterior negativity (LAN) related to early syntactic parsing processing (Friederici, Wang Herrmann, Maess & Oertel, 2001) or to the N400 related to semantic integration problems (Simos, Basile & Papanicolaou, 1997; Halgren, Dhond, Christensen, van Petten, Marinkovic, Lewine & Dale, 2002). So far, there are no published MEG studies related to the later ERP component, the P600 indexing syntactic re-analyses processes.

Friederici and colleagues (2001) investigated the localization of neural generators involved in early syntactic parsing processes in German using MEG by measuring the brain's response to the detection of a phrase structure violation realized as a category error (The fish was caught vs. The fish was *in caught.). Dipole source localization was performed using a realistically shaped standard volume conductor model with fMRI constraints. The results show that the early syntactic parsing processes are supported by activation within the temporal regions, possibly the planum polare, as well as by fronto-lateral regions. These regions are activated bilaterally with dominance in the left hemisphere, which was indicated by dipole strength. The contribution of the left temporal regions to the early syntactic processes seems to be larger than that of the left fronto-lateral regions. The authors concluded that the early syntax-related ERP component with its left anterior distribution is not due to a left frontal generator alone, but it seems to originate from both a frontal and a temporal generator.

With respect to pure semantic processing, Simos and colleagues (1997) aimed to localize the sources of the N400 response elicited in a sentence-reading paradigm. Half of the sentences ended with a semantically appropriate word (e.g. 'He dried his hands with a towel.'), while the other half had inappropriate endings (e.g. 'He dried his hands with a hammer.'). Evoked magnetic fields that were recorded over the left hemisphere showed clear magnetic field extrema during the time course of the N400. The authors reported dipole regions in temporal lobe structures, in the vicinity of the hippocampus and the parahippocampal gyrus (in two subjects) and in posterior temporal regions (in the vicinity of the middle temporal gyrus; in five subjects). The authors stated that these findings are consistent with the view that posterior association cortices in the left hemisphere are involved in word recognition and semantic comprehension during reading. These findings are also supported by a more recent whole

head MEG study (Halgren et al., 2002). Halgren and colleagues (2002) also investigated sentence endings with semantically congruent or incongruent words. Sentence-terminal incongruent compared to congruent words evoked a large magnetic field over the left hemisphere; peaking at approximately 450ms after stimulus onset. Source modeling at this latency with conventional equivalent current dipoles (ECD) placed the N400(m) generator in or near the left superior temporal sulcus as has been found by Simos and colleagues (1997). A distributed solution constrained to the cortical surface suggested a sequence of differential activation. Using this method the authors found more activation for incongruent compared to congruent words beginning in planum temporale at approximately 250ms, spreading to anterior temporal sites (Wernicke's area) at approximately 270ms, and then by ~300ms to left prefrontal areas (Broca's area). One conclusion from these results was that brain activity that is generated in multiple extended locations may be more realistically modeled using anatomically constrained distributed sources, as opposed to standard ECD.

Based on the reported findings, higher current densities are expected over temporal as well as frontal areas for incongruent pronouns compared to congruent pronouns within the person-condition between 250-400 ms, and possibly later magnetic maxima between 400-600ms at similar regions. On the other hand, pure syntactic information processing measured via thing-sentences, should reveal increased current densities at temporal and frontal regions predominantly at the left hemisphere between 400-600ms.

3.2 Methods

Subjects and material

Twenty-one subjects volunteered for paid participation in the experiment. Nine datasets could not be used due to too many artifacts, i.e. moving, eye blinks etc. or technical problems. The final population of subjects comprised twelve native speakers of German, age range 20 to 30, mean age 23.8 years, 5 women. All subjects had normal or corrected-to-normal vision, were right-handed according to self-report and neurologically healthy.

For material and procedure description, the reader is referred to Chapter 2, Experiment 1 (pp. 32-33).

Figure 3.1 MEG responses for congruent (black) and incongruent (red) pronoun referring back to a Person are shown at 148 gradiometer channels. Signals from six gradiometers are shown in expanded format at the upper left.

Figure 3.2 MEG responses for congruent (black) and incongruent (red) pronoun referring back to a Person are shown at 148 gradiometer channels. Signals from six gradiometers are shown in expanded format at the upper left.

Recording and analysis

The MEG signals were recorded using a BTi Magnes 2500 whole-head MEG magnetometer system with 148 sensors (Biomagnetic Technologies, Inc.). The MEG signals were filtered with a bandpass of DC 50 Hz and digitized with a sampling rate of 254 Hz. Additionally, thirty-two surface points on the subject's head were digitized to match the MEG head coordinate system with individual T1 weighted magnetic resonance images using

BrainVoyager 2000. Spatio-temporal source analysis was performed using the BESA2000 software (MEGIS Software GmbH). The center of the spherical conductor model was set to 5 mm superior and 5 mm anterior to the posterior commissure based on each subject's MRI. Artifact rejection was performed offline by an automated procedure. Trials including artifacts, such as eye-movements, were rejected from further analysis. By averaging the remaining artifact-free epochs per condition, the event-related fields (ERF) for each condition were derived. The mean number of trials contributing to the average was 83 (person congruent and person incongruent conditions), 86 (thing congruent) and 82 (thing incongruent condition). Then, we calculated difference waves (incongruent minus congruent) as a basis for sources analysis. For source estimation of these difference waves, we then used the minimum norm estimation (MNE, Hämäläinen et al., 1993; Dale & Sereno, 1993) method as a linear estimation technique that does not make explicit assumptions about the number of active sources and their approximate locations and thus objectively models the current sources underlying the magnetic response. The MNE has been proposed by Tichonov & Arsenin (1977), and has been further elaborated by Dale & Sereno (1993). This approach originates from statistical estimation theory. Compared to the traditional ECDs, this method achieves a better solution to the inverse problem of localizing cortical activity in the brain from surface

Figure 3.3 MEG responses for all conditions (black: Person; grey: Thing; and solid line: congruent pronoun; dashed line: incongruent pronoun) at gradiometer channel A035 (left temporal position).

Figure 3.4 Difference waveforms (incongruent minus congruent) are shown for critical pronouns for Person sentences (left panel) and for Thing sentences (right panel) superimposing all subjects.

recordings by revealing a unique constellation of current elements modeling the recorded magnetic field distribution with the smallest amount of overall current. To find a good estimation on neural generator locations, MNE assumes a priori, among other assumptions that the dipole strength and the noise strength have a certain statistical distribution across the sensors. For example, it seems plausible to assume that the strength of dipoles and the strength of noise co-vary between neighbored sensors (source covariance). The calculated estimation is then compared with the observed data, such that in a linear case, one aims to find the linear operator which minimizes the expected difference between the estimated and the correct solution.

3.3 Results

Fields

Figures 3.1 and 3.2 show the MEG signals to critical pronouns. All conditions reveal an early negative deflection at about 100 ms followed by a positive deflection peaking at about

Figure 3.5 Average of Current Minimum Norm Estimates (MNE) for the difference waves of pronouns (incongruent minus congruent) referring back to persons (left panel) or things (right panel) based on a spherical head model cortical activity from 200 to 650 ms in steps of 50 ms are shown. On top, one sees the respective butterfly plot (all channels superimposed) for the difference waves of the ERFs.

150 ms. The waves than are identical for all conditions in the time window 150-300 ms after word onset. Between 300 and 400 ms incongruent and congruent conditions show a difference with incongruent ones being more positive than congruent ones. These holds for both sentence types, especially at sensor sites A076/77, A054/55, A034/35. An overlay of the signal from all condition, displayed in Figure 3.3 at A035 indicates that the overall violation effect is larger for person compared to thing conditions. It also shows that the two congruent conditions differ from each other.

Waveforms were quantified by mean amplitudes in the time-windows from 300 to 400 ms for the N400m and from 400-600 ms for the electromagnetic counterpart of the P600 (P600m) for a selected set of magnetometers based on visual inspection, namely A005, A006, A007, A017, A018, A019, A020, A034, A035, A036, A054, A055, A056, A076, and A077. These were subjected to repeated measures analysis of variance that included the Factors Antecedent (Person vs. Thing), Congruency (congruent vs. incongruent) and Magnetometers (15 channels). For the N400m time-window no main effect for Antecedent ($F(1,11) = 0.31, p > .55$), and Congruency ($F(1,11) = 0.22, p > .6$), and no interaction between Antecedent and Congruency ($F(1,11) = 0.02, p > .8$) was found. Also, within the 400–600 ms time-window no significant effects were found (Antecedent: $F(1,11) = 0.31, p > .5$; Congruency: $F(1,11) = .22, p > .6$; Antecedent x Congruency: $F(1,11) = 0.02, p > .8$).

Figure 3.4 shows an overlay of all subject's difference waves of person and thing conditions (incongruent minus congruent pronouns) indicating a large variance between subjects. This large variance explains the insignificant results of statistical analysis even though there seemed to be effects visible in Figure 3.1 and 3.2.

Minimum Norm Estimates

Figure 3.5 shows the calculated Minimum Norm Estimates (MNE) for the difference waves (incongruent minus congruent) of person- (left panel) and thing-antecedents (right panel) from 200 to 650 ms in 50 ms steps. The operator solutions, which minimized the difference between estimated and observed solution are plotted in % match. At an early stage (200 ms), the person conditions show an increase in activity for incongruent compared to congruent pronouns at right parietal sites (Figure 3.5, left panel). Later on (400 ms) there is a left-sided increase of temporo-parietal activation. After that time point, the process of co-reference seems to be finished according to MEG-measurements. For the thing sentences (Figure 3.5, right panel) there is an increase in MNE for incongruent compared to congruent pronouns at about 400ms at right parietal areas. Additionally, there seems to be activation within the

cerebellum and the spinal cord. This activation seems to be unreliable out of a structural point of view.

3.4 Discussion

The current study was set up to find the electromagnetic counterparts to the ERP effects observed in the first experiment. There, a P600 was found for incongruent compared to congruent pronouns within person- and thing-sentences. This effect was larger for person pronouns compared to thing pronouns. The P600 is known to be an index for syntactic processing problem, re-analysis, or error detection. Furthermore, in chapter one it was proposed that the P600 may be influenced by semantic information as well.

The literature concerning MEG experiments investigating sentence-processing reveals that the N400(m) generator detected via standard ECD localization was found in or near left superior temporal sulcus (Simos et al., 1997; Halgren et al., 2002). Halgren and colleagues additionally investigated a distributed solution and found a more complex network for semantic integration problems, namely beginning in planum temporale at approximately 250ms, spreading to anterior temporal sites (Wernicke's area) at approximately 270ms, and then by ~300ms to left prefrontal areas (Broca's area). In contrast, investigations concerning the well-known P600 ERP-component are not published to the author's best knowledge.

For the present MEG experiment, no reliable differences between incongruent and congruent pronouns were found, neither in person nor in thing sentences in any of the tested time-windows. Nevertheless, we would like to go into the solutions of the MNE as a descriptive approach, taking them as a tendency (ignoring brainstem and cerebellum activation due to regional implausibility). For incongruent relative to congruent pronouns referring back to a person (encountering biological and syntactic gender information; Figure 3.5, left panel) we found that the processing of semantic in combination with syntactic gender violation started early at right temporal sites (200 ms). This right hemispheric generator is contrary to earlier results found for early syntactic generators (Friederici et al., 2001) and semantic integration problems (Halgren et al., 2002), who detected predominantly left hemispheric generators or for one female subject a right asymmetry (Friederici et al., 2001). Due to the weak statistical reliability for the recent study, we should not go into details to this right hemispheric asymmetry for early activation. However, at a later point (400 ms) we observed a left temporo-parietal activation, followed by a right hemispheric parietal activation. The

activation of this region is in accordance with results of previous studies of semantic integration problems as revealed by i.e. Halgren and colleagues (2002) or an imaging study using the same experimental material (chapter 4 this volume). In contrast, incongruent compared to congruent thing pronouns revealed a different activation pattern (encountering solely syntactic gender information, Figure 3.5, right panel): At about 400ms a difference activation for thing-conditions (incongruent minus congruent) was found at right parietal sites (Figure 3.5). In comparison to the person-case, processing of thing-pronouns (viz. violation of solely syntactic gender information) starts later on and is located at different areas, namely right parietal sites.

Solely looking at the ERF-results, one could conclude that the experimental pronoun manipulation did not reliably effect syntactic or semantic processing. However, the ERP results reported in the second chapter showed that the given pronoun manipulation is a reliable method to investigate syntactic and semantic gender information processing during pronoun resolution. But then, why is the MEG method not sensitive to the given manipulation? This may be related to physical characteristics underlying MEG measurements. For example, Eulitz and colleagues stated that the same cognitive process might be differentially imaged by MEG and EEG (Eulitz, Eulitz & Elbert, 1997). EEG measurements result from the extracellular volume currents triggered mainly by postsynaptic potentials. In contrast, MEG is thought to arise from the intracellular branch of this process, i.e. from currents that flow from the dendrites to the axon terminals. Thereby, MEG is mainly sensitive to currents flowing tangentially (Williamson & Kaufman, 1990) to the surface of the scalp and to a lesser degree to radial sources (Lütkenhöner, Menninghaus, Steinsträter, Wienbruch, Gißler & Elbert, 1995). Consequently, EEG and MEG are affected differentially by averaging due to a stronger reduction of 'biological noise' for tangential sources than for radial ones. 'Biological noise' in this case means that if sources vary across trials and appear in different cerebral regions from trial to trial, their impact on event-related brain responses will be suppressed by averaging. However, this 'biological noise' is generally more strongly reduced for tangential sources than for radial ones. Sources in most of the sensory projection areas are primarily tangentially oriented. Consequently, such sources, which are typically activated early in the information processing, have a better signal-to-noise ratio for MEG measurements than for EEG measurement. In cases where the 'tangential' noise is strong, and sources are mainly radial, EEG might prove to be the more valuable source of information.

When higher processing stages are the interest of investigation, such as language processing as reported here, the corresponding sources may be widely distributed, and currents flowing

simultaneously in opposing walls of a sulcus may partially cancel each other out. The remaining equivalent current dipole may have a stronger radial than tangential orientation (Lutzenberger, Elbert & Rockstroh, 1987) and thus will appear with a relatively greater weight in EEG than MEG responses as we could see in the present data set.

When sex meets gender on a neural basis

Abstract

We used event-related functional magnetic resonance imaging (erfMRI) to investigate the neural basis of biological and syntactic gender integration during pronoun processing in German. German allows separating both processes experimentally. Overall, syntactic processing activated areas adjacent to Broca's area (BA44), whereas processing of the biological sex involved the supramarginal gyrus (BA39) in addition. A comparison with event-related potentials elicited with identical material suggests that the information is integrated 400-700 ms after target onset, visible in both cases as a P600 with different effect sizes. The results illuminate temporal and spatial integration of syntactic and semantic processing during the establishment of co-reference between a pronoun and its referring noun.

4.1 Introduction

Reading emails, newspapers, letters of friends or books is one of our daily businesses. Usually, we are not aware of the details of this cognitive task because it goes so well, mostly automatic. Among other things, in order to understand the message, we have to integrate the meaning and the syntactic relations among single words. For example, in “The woman is happy because she is in love” the pronoun “she” refers back in meaning and syntax to the referent “woman”. Thus, pronouns are sophisticated language devices that allow a speaker to refer to an earlier mentioned person or thing. In order to establish this reference, pronouns have to match the conceptual meaning (biological gender), if available, and the syntax of the noun (syntactic gender). In the German language, ‘the woman’ (‘die Frau’) for example has a female biological gender with a corresponding feminine syntactic gender. However, ‘the jacket’ (‘die Jacke’) has just an (arbitrary) feminine syntactic gender with no semantic gender reflex. Due to this richness of gender properties in German nouns, German pronouns are well-suited language elements to investigate the contribution of semantic and syntactic processing because one can disentangle biological and syntactic gender information experimentally. We used this dissociation to investigate the involvement of semantic and syntactic information processing to the establishment of co-reference.

How are pronouns integrated into a sentence? Garrod and Sanford (1994) presented a model with two stages for pronoun interpretation (see also Garrod & Terras, 2000) with (1) a *bonding or immediate recovery stage*, which is an automatic, more syntax-related process associated with establishing a link between pronoun and a previous expression, and (2) a *resolution or immediate integration stage*, which involves testing and resolving this link. The integration is responsible for evaluating the established link, i.e. by weighting syntactic and semantic discourse information. In case of congruency, the integration process finishes with a so-called commitment. In case of incongruency, the integration process fails or is delayed. So far, pronoun processing has been investigated with reaction time and event-related potentials (ERP). In a preceding ERP-study (Hammer et al., 2005) we performed the identical experiment as in the present fMRI study with different subjects (for example material see Table 4.1). The conditions revealed a classical P600 pattern, i.e. the ERP signal were more positive during the processing of gender for incongruent compared to congruent pronouns. This P600 effect was larger for person- compared to thing-conditions. The results were interpreted as reflecting the integration of the pronoun into sentence context. We suggested

that the larger P600 in the person-condition reflects integration of both biological and syntactic gender information, whereas the smaller P600 in the thing-condition reflects syntactic gender information proper.

Because there are no earlier imaging studies on pronoun processing, we would like to review some work engaging syntactic and semantic processing during language comprehension.

Indefrey and colleagues (2001) investigated the detection of syntactical errors in meaningless sentences consisting of pseudo words, as in "der Donk der die Feumern lomt *telchen das Grumel. (The [singular] donk who lomes the feumers *telch [plural] the grumel.)" Their data revealed that in syntactic error detection an area of the left dorsolateral prefrontal cortex is specifically involved in syntactic processing aspects of language.

Semantic processing was investigated by Kiehl, Laurens, and Liddle (2002). Subjects read sentences that ended with either a congruent or an incongruent word with previous sentences context. This paradigm is known to elicit an N400 component in event related potential (ERP) research. Example material would be: "The dog caught the ball in his MOUTH." (congruent). "They called the police to stop the SOUP." (incongruent). The subjects' task was a 'makes sense or no-sense' discrimination task related to the last word written in upper case letters. An increase of the Blood oxygen level-dependent (BOLD) response was found in bilateral inferior frontal and inferior-medial temporal cortex, left lateral frontal cortex, left posterior fusiform gyrus, bilateral motor cortex, and supplementary motor area. These findings were discussed as these areas relate to the localization of the cerebral sites underlying semantic processing. In a recent study Hagoort, Hald, Bastiaansen, and Petersson (2004) investigated semantic integration and general world knowledge. Subjects read sentences like: "Dutch trains are *yellow/white/sour* and very crowded." (Critical words are in italic; true, violation of world-knowledge, semantic violation.) Hagoort and colleagues found that the inferior prefrontal cortex is involved in the integration of both, meaning (semantic) and world knowledge.

Other researchers investigated the processing of syntactic and semantic processing within the same experiment. For example, in a study performed by Newman, Pancheva, Ozawa, Neville, and Ullman (2001) subjects read well-formed sentences randomly intermixed with sentences which either contained violations of syntactic structure ("Yesterday I cut Max's apple with caution." vs. "Yesterday I cut Max's with apple caution.") or were semantically implausible ("Yesterday I sailed Max's boat to china." vs. "Yesterday I sailed Max's hotel to china."). The authors reported that syntactic violations elicited significantly greater activation than semantic violations primarily in superior frontal cortex. Semantically incongruent sentences

elicited greater activation than syntactic violations in the left hippocampal and parahippocampal gyri, the bilateral angular gyri, the right middle temporal gyrus, and the left inferior frontal sulcus. These results were interpreted to demonstrate that syntactic and semantic processing result in non-identical patterns of activation, including greater frontal engagement during syntactic processing and larger increases in temporal and temporo-parietal regions during semantic analyses. Röder, Stock, Neville, Bien, and Rösler (2002) used fMRI to investigate the neuroanatomical correlates of semantic and syntactic functions and possible interdependencies between the related brain systems. In a completely crossed design they varied syntactic processing demands (easy vs. difficult to process word order sequences) and the meaningfulness of sentences (real- vs. pseudo-word sentences). Semantic in contrast to pseudo-word sentences elicited a stronger activation in inferior frontal gyrus, and superior and middle temporal gyrus. Syntactic difficulty had its strongest effect within the left inferior frontal region and this effect was more pronounced for semantic than non-semantic speech. The authors interpreted their findings that semantic and syntactic language functions are mediated by partly specialized brain systems but that there nevertheless is a substantial functional overlap of the involved brain structures, especially in left inferior frontal regions. Friederici, Rüschmeyer, Hahne and Fiebach (2003) investigated brain areas supporting the processing of sentence-level semantic and syntactic information. Hemodynamic responses were recorded while subjects listened to correct (i.e. 'Das Hemd wurde gebügelt.' The shirt was ironed.), syntactically incorrect (i.e. 'Die Bluse wurde am* gebügelt.' The blouse was on ironed.), and semantically incorrect sentences (i.e. 'Das Gewitter* wurde gebügelt.' The thunderstorm was ironed.). The authors reported that both anomalous conditions recruited larger portions of the superior temporal region than correct sentences. Processing of syntactic violations specifically involved the anterior portion of the left superior temporal gyrus, the left posterior frontal operculum (adjacent to Broca's area) and the putamen in the left basal ganglia, whereas processing of semantic violations relied primarily on the mid-portion of the superior temporal region bilaterally and the insular cortex bilaterally. Comparing the two incorrect conditions the authors found higher levels of activation for the syntactic compared to semantic condition in the left basal ganglia and for the semantic compared to the syntactic condition in the bilateral mid-portions of the superior temporal gyri. These data indicate that both semantic and syntactic processes are supported by a temporo-frontal network with distinct areas specialized for semantic and syntactic processes.

Figure 4.1 (A) Activated voxels as revealed by the across subject ($n=11$) analysis (GLM) for Person-effect. Contrast: incongruent minus congruent sentences in this and the following figure. The activations are overlaid onto a single subject's brain (coronal view at Y 3, 17 and -49). For detailed Talairach space information see Table 4.2. (B) The middle part in each panel shows the event-related average time course of the BOLD response for the following regions of interest: left (LH) and right (RH) inferior frontal gyrus (GF_i), left and right supramarginal/angular gyrus (Gsm/Ga), and medial frontal gyrus (GF_m). (C) Activated voxels as revealed by across subject ($n=11$) analysis (GLM) after cortex-based inter-subject alignment based on gyral/sulcal pattern of individual brains for the biological and syntactic gender incongruity effect for Person-sentences. For beta-weights see Figure 4.3, Panel A.

Taken together, the reported studies reveal an unclear pattern of syntactic and semantic information processing during language comprehension. But still, there are some similarities within these studies. For syntactic processing nearly all studies reported an involvement of the left prefrontal cortex. However, semantic processing was reported to be found within left frontal areas, parietal and temporal regions. Two studies reported a bilateral activation for semantic processing (Kiehl et al., 2002; Newman et al., 2001).

The present *erfMRI* study uses a violation paradigm, which is well established in the event-related potential literature (Osterhout et al., 1997; King & Kutas, 1997; Schmitt et al., 2002, Hammer et al., 2005) to investigate pronoun processing. By using German, we can differentiate semantic/biological and syntactic gender information and observe their contributions and possible interactions. German subjects read sentences in which an antecedent was either a person or a thing. This antecedent was introduced in the first phrase. In the second phrase a pronoun was presented which either referred back to the antecedent in the first phrase (congruent pronoun) or which was incongruent with the antecedent. Example sentences are displayed in Table 4.1.

Antecedent	Congruency	Example sentence
PERSON	congruent	Die Frau _{FEMALE} ist beliebt, weil sie _{FEMALE/feminine} schön ist.
	incongruent	Die Frau _{FEMALE} ist beliebt, weil er _{masculine} schön ist.
THING	congruent	Die Jacke _{feminine} ist warm, weil sie _{feminine} gefüttert ist.
	incongruent	Die Jacke _{feminine} ist warm, weil er _{masculine} gefüttert ist.

Table 4.1 Example material. Translation: Person - The woman is popular because she/he is beautiful. Thing - The jacket is warm because she/he is lined; capital letter = sex, small letter = syntactic gender.

Based on findings reported in the literature reviewed above, we expected an increase of BOLD response in inferior frontal, parietal and temporal regions for incongruent relative to congruent person-sentences (biological and syntactic gender), whereas for incongruent relative to congruent thing-sentences (solely syntactic gender information) we assumed to find activation in inferior frontal regions mainly in the left hemisphere.

Figure 4.2 (A) Activated voxels as revealed by the across subject ($n=11$) analysis (GLM) for Thing-effect. The activations are overlaid onto a single subject's brain (sagittal view at X -40, and coronal view at Y -25). For detailed Talairach space information see Table 4.2. (B) Event-related average time course of the BOLD response for the following regions of interest: GF_i, LH, GF_m LH, and superior temporal sulcus (ST_s). (C) Activated voxels as revealed by across subject ($n=11$) analysis (GLM) after cortex-based inter-subject alignment based on gyral/sulcal pattern of individual brains for the syntactic gender incongruity effect for sentences with Things as antecedent. For beta-weights see Figure 4.3, Panel B.

Figure 4.3 Responses to congruent and incongruent Person (A) or Thing (B) sentences in regions of interest as reflected in the linear-regression standardized b weights (β estimates) averaged across subjects (A1 for person condition, and B1 for thing condition). Black bars represent congruent sentences and white bars represent incongruent sentences. Additionally, the difference (incongruent minus congruent) of b weights for each individual subject is shown in panel A2 and B2. Error bars indicate the standard errors of the average b weights.

4.2 Results

For the person-condition (Figure 4.1) the incongruent sentences elicited a larger BOLD response change than congruent sentences in two areas on both hemispheres, namely the inferior frontal gyrus (GFi, BA44/48) and the supramarginal/angular gyrus (Gsm/Ga, BA39/40) and portions of the left medial frontal gyrus (GFm, BA6) reflecting a complex

processing of biological and syntactic gender information for pronouns. Furthermore, the averaged time courses of the BOLD response showed that there was no response for congruent person-sentences on the right hemisphere, indicating that the right hemisphere was only sensitive to incongruent sentences. For the thing-condition (Figure 4.2) the incongruent sentences led to a larger BOLD signal change than congruent sentences in three areas in solely the left hemisphere, namely the GFi (BA44/48), the GFm (BA6) and the STs (BA21) reflecting a pure syntactic gender information processing. For details of ROI statistic the reader is referred to Table 4.2.

Name of ROI	BA	Size Nr. of voxel	Talairach			Contrast	
			x	y	z	t	p
Person (i-c)							
GFi (LH)	44/48	1302	-40	17	21	5.7	.000001
GFi (RH)	44	1802	49	12	17	6.3	.000001
GFm (LH)	6	211	-43	3	53	4.7	.000003
Gsm/Ga (LH)	39/40	647	-47	-49	38	4.3	.00002
Gsm/Ga (RH)	39	3232	49	-58	29	5.7	.000001
Thing (i-c)							
GFi (LH)	44/48	4552	-40	22	7	6.4	.000001
GFm (LH)	6	536	-36	3	52	5.3	.000001
STs (LH)	21	1245	-47	-25	-2	6.6	.000001

Table 4.2 ROI details. Activated areas from the fMRI experiment. All regions reported are listed here and provided with presumed Brodman areas (BA); voxel size; Talairach coordinates as defined by Talairach and Tournoux (1998; x: left-right; y: anterior-posterior origin in anterior commissure; z: inferior-superior) and statistic values for specific contrasts (t, p). Abbreviations: LH: left hemisphere; RH: right hemisphere; GFi, inferior frontal gyrus; GFm: medial frontal gyrus; Gsm: supramarginal gyrus; Ga: angular gyrus; STs: superior temporal sulcus.

4.3 Discussion

The aim of the study was to disentangle syntactic and biological/semantic gender information processing during pronoun processing as exemplified by the sentences "Die Frau ist beliebt, weil sie/*er* schön ist." (semantic/syntactic gender information and its violation, incongruent pronoun is in italic font) and "Die Jacke ist warm, weil sie/*er* gefüttert ist." (syntactic gender information and its violation). Sentences with pronouns referring back to a person revealed an increase of BOLD response for incongruent compared to congruent pronouns in bilateral areas within the inferior frontal gyrus (GFi), and the supramarginal/angular gyrus (Gsm/Ga), and the left medial frontal gyrus (GFm). In contrast, sentences with pronouns referring back to things showed a larger BOLD response for incongruent compared to congruent pronouns in the left GFi/GFm and left superior temporal sulcus (STs). These findings are generally

consistent with earlier findings for semantic (i.e. Kiehl et al., 2002; Newman et al., 2001), and syntactic processing (i.e. Indefrey et al., 2001; Newman et al., 2001; Röder et al., 2002).

Furthermore, Röder and colleagues reported an interaction of syntactic and semantic manipulation within the left inferior frontal gyrus. The authors suggested that this finding supports the idea that brain areas show some processing specificity, although both language aspects seem to be supported by overlapping brain systems.

Our data support this result as we found an activation of the left GFi for both, Person- and Thing-effect.

It might be fruitful to consider the results from our earlier ERP-study (Hammer et al., 2005) with the identical experimental material because ERPs can give insights into the temporal domain of cognitive processes. In general, both violation conditions revealed a P600 effect within the time-range of 400-700 ms after pronoun onset, with incongruent pronouns being more positive than congruent pronouns suggesting syntactic gender information processing for building up co-reference between pronoun and antecedent. However, this effect was double-sized for the person compared to Thing cases, indicating that the P600 might be a response to reanalysis of the sentence including both syntactic and semantic information processing. Therefore we can conclude that semantic and syntactic integration take place in parallel, i.e. at the same time.

Together, the ERP and fMRI data show a clear pattern of pronoun processing: in the person-case the language system appears to use both biological and syntactic gender information reflected by an activation of GFi and Gsm/Ga on both hemispheres and the left GFm, seen as a larger BOLD signal change in those areas for incongruent compared to congruent gender sentence types (see Figure 4.1), and in a preceding ERP study using identical material in a large P600 (see Figure 4.4, upper panel). In contrast, for the pure syntactic thing-case, the processing of syntactic violation is reflected by activation of the left GFi, GFm and STs (see Figure 4.2), and as shown in the ERP signal as a comparably small P600 (see Figure 4.4, lower panel).

Figure 4.4 Grand average ERPs time locked to the onset of the critical pronoun at electrode P4 (negativity is up and each hash mark represents 200 ms of activity, 16 subjects, published in Hammer et al., 2005). The upper panel shows the ERPs to pronouns in sentences with a person as an antecedent and the lower panel displays the ERPs to pronouns in sentences with a thing as an antecedent. Congruent pronouns are represented by a solid line and incongruent pronouns by a dashed line.

How can this observed difference in pronoun processing for person vs. thing sentence types be explained? As mentioned in the introduction, Garrod and Sanford (1994, see also Garrod and Terras, 2000) presented a cognitive model with two stages for pronoun interpretation with (1) a low level automatic “bonding” process, and (2) a “resolution” stage. Reading a German sentence with a pronoun the comprehender has to go through (1) syntactic match in terms of syntactic gender marking and possibly (2) a semantic match in terms of biological gender marking between pronoun and antecedent. We think that our ERP and the *erfMRI* data present neurophysiological evidence to support this theoretical framework. Pronouns referring to persons can be matched to the antecedent by biological and syntactic information requesting more processing capacity indicated by the large P600 and the activation of two cortical areas, the bilateral GFi and Gsm/Ga. In contrast, pronouns referring back to things are matched by pure syntactic gender information resulting in a smaller P600 indicating less processing activity and an activation of the left GFi and left STs.

4.4 Methods

Subjects

For the present study we collected *fMRI* images from eleven subjects (mean age 28 ± 5 years; 4 male, 7 female) while they read the above-described sentences presented in a rapid event-related design method (Dale & Buckner, 1997; Buckner, Bandettini, O’Craven, Savoy, Petersen, Raichle & Rosen, 1996). All subjects gave their written consent, and were paid for participation.

Material

One-hundred-twenty sentences, 60 about persons and 60 about things were constructed. Each sentence had two clauses. The first clause in each sentence was the main clause, which described a state of a person or a thing. The person or the thing was the subject of the main clause, and formed the antecedent of the pronoun following later. Care was taken to guarantee equal word frequencies for persons and things using the CELEX-database (Baayen et al., 1995). The second clause was a subordinate clause introduced by the conjunction *weil* (*because*). This conjunction was followed by the critical word, a pronoun referring to the person or the thing. All sentences were then copied and the congruent pronoun was replaced

by a pronoun that was incongruent in terms of biological and syntactic gender in the person condition and by syntactic gender in the thing condition (see Table 1 for examples).

A trial started with a fixation cross in the middle of the screen, presented a duration that varied one to five times the Time to Repeat (TR = 1920 ms) of image acquisition, and was followed by the word-by-word presentation of the sentence. Each word was presented for 350 ms with a 250 ms inter-stimulus interval. Sentence ending words were presented with a period indicating the end of a sentence.

Functional measurement

We measured 24 transversal slices at 3 Tesla (Magnetom Trio, Siemens) using an echo-planar-imaging sequence. The pulse-sequence parameters were as follows: plane resolution, 3,5 x 3,5 x 3,5 mm; gap, 1,2; field of view (FOV), 224 mm, acquisition matrix 64 x 64; time to repeat (TR), 1920 ms; time to echo (TE), 35 ms; flip angle (FA), 75°. One functional run consisted of 375 volumes. In order to avoid a T1 saturation effect we did not present any material during the first 10 volumes and excluded the first four volumes from further analyses.

Anatomical measurements

Each subject underwent a high resolution T1-weighted anatomical scan at 3 Tesla (Magnetom Trio, Siemens) using a three-dimensional T1-fast-low-angle shot sequence lasting 9 min and 50 sec (192 slices; slice thickness, 1 mm; TR, 2300 ms; TE, 3,93 ms; FA, 8°; FOV, 256 mm; matrix, 256x256).

Analysis

Data analysis included preprocessing (3D motion correction, spatial smoothing and temporal filtering), coregistration, Talairach transformation of scans, volume and surface rendering, and cortex reconstruction using BRAINVOYAGER 2000 and BRAINVOYAGER QX software. For multiple regression analysis of the functional data, a general linear model (GLM) with predictors for each experimental condition was computed. Using contrast (t) maps, significant differences between conditions were assessed. Multiple comparisons were controlled by the False Discovery Rate (FDR) approach at a level of $q=0.05$ (Genovese, Lazar & Nichols, 2002). Reported activations are based on fixed effects group statistics.

In order to increase the sensitivity of statistical analysis, an improved alignment of the brains was achieved by a cortical inter-subject alignment procedure. A polygon mesh of each

cortical hemisphere was obtained by segmenting and tessellating the white/grey matter boundary (Dale & Sereno, 1993; Fischl, Sereno & Dale, 1999; Kriegeskorte & Goebel, 2001). Then, cortical time-courses were created by sampling the functional time-series at positions corresponding to the nodes of the cortical mesh. Polygon meshes (and corresponding cortical time-courses) were morphed into alignment using spherical representations of the cortical sheet (Fischl, Sereno, Tootell & Dale, 1999). For thresholding the equivalent t-values to the FDR analysis were chosen ($T > 3.5$).

Interaction of semantic and syntactic information and working memory during pronoun resolution: an ERP study

Abstract

Personal pronouns are used to refer back to an earlier mentioned person or thing. In German, this co-reference can be based on syntactic and/or semantic gender information. The aim of this study was to investigate the interaction of demands on verbal working memory (VWM) and syntactic and semantic information during the process of building up co-reference between a pronoun and its antecedent. Healthy young subjects were subjected to a word by word reading paradigm in conjunction with the recording of event-related potentials (ERP). We experimentally disentangled syntactic and biological/conceptual gender information by using German sentences either about a person (biological and syntactic gender assignment) or about a thing (syntactic gender assignment) followed by a pronoun congruent or incongruent in terms of gender. Additionally we manipulated VWM by increasing the distance across noun phrases between pronoun and antecedent resulting in a short distance (SD) and a long distance (LD) VWM condition. In general this VWM manipulation affected the ERP N400/P600 patterns of our sentence types indicating that VWM interacts with semantic and syntactic processing. For sentences with persons as antecedent in SD conditions we found an N400 effect for incongruent compared to congruent pronouns, indicating involvement of semantic integration. In contrast, for LD conditions we observed a P600 but no N400 effect indicating the involvement of syntactic reanalysis without independent semantic integration. Since this effect was larger for LD person compared to SD thing conditions, we interpreted this finding as reflecting increased processing difficulty due to temporal distance and double gender violation (biological/syntactic). For sentences with things as antecedent, within SD conditions we found a P600 effect indicating an involvement of syntactic reanalysis, whereas LD conditions revealed no effect indicating no different processing of incongruent and congruent pronouns in that case. In addition, we found an N400 on the word following the pronoun for SD and LD thing sentences, indicating an ongoing search process for i.e. an actor outside sentence context independent of distance manipulation. In general, our different N400/P600 patterns on pronoun position suggest that a parser switches preference between semantic and syntactic information access during pronoun processing depending on VWM and information availability.

5.1. Introduction

Personal pronouns are linguistic devices which allow us to refer back to an earlier mentioned person or thing in the discourse and thus creating coherence in written or spoken language. Considering the sentence “The woman is smiling because she is happy.” it is easy to tell that *she* belongs to the woman in this sentence. Several cognitive models outline the details of this process (Garrod & Sanford, 1994; Graesser, Millis & Zwaan, 1997; Gordon & Hendrick, 1998). Garrod and Sanford (1994) presented a model with two stages for pronoun interpretation (see also Garrod & Terras, 2000) with (1) a bonding or immediate recovery stage, which is an automatic, more syntax-related process associated with establishing a link between anaphor and a previous expression, and (2) a resolution or immediate integration stage, which involves testing and resolving this link. The integration stage is responsible for evaluating the established link, i.e. by weighting syntactic and semantic discourse information. In case of congruency, the integration process finishes with a so-called commitment. In case of incongruency, the integration process fails or is delayed.

But how does the reader’s brain link a pronoun to the antecedent? Event-related potentials (ERP) are a suitable method to investigate cognitive processes especially in the temporal domain. ERP research of the last decades has shown that semantic integration problems elicit a negative deflection with a peak around 400 ms and a right central-parietal negative maximum for incongruent compared to semantically congruent words, the so-called N400 component (Kutas & Hillyard, 1980, 1983). Problems with syntactic integration become manifest in a positive shift that starts at about 400 to 500 ms after word onset, the so-called P600/SPS effect (Osterhout & Holcomb, 1992; Hagoort et al., 1993). In addition, it has been shown that syntactic processing problems can give rise to an earlier left anterior negativity (LAN) (e.g. Kluender & Kutas, 1993; Friederici, Hahne & Mecklinger, 1996). These frontal negative ERP effects in general are observed under conditions of increased working memory load in sentence (Kluender & Kutas, 1993; Carpenter, Miyake & Just, 1995; Münte et al., 1998b; Streb et al., 1999; Fiebach et al., 2001) as well as discourse processing (Graesser et al., 1997; van Berkum et al., 2003). Negativities with a similar distribution have also been observed for syntactic violations (Friederici et al., 1996; Münte et al. 1993).

ERP studies on pronoun processing have shown that a disagreement in syntactic gender information between pronoun and antecedent reveals a P600/SPS compared to congruent gender information indicating an involvement of syntactic gender information processing

(Osterhout & Mobley, 1995; Schmitt et al., 2002; Hammer et al., 2005). On the other hand, a disagreement in biological/conceptual gender reveals an N400 (King & Kutas, 1997), and a disagreement in biological and syntactic gender reveals either an N400/P600 complex (Schmitt et al., 2002) or a P600 which is twice the size of a syntactic gender violation condition (Hammer et al., 2005).

In order to be able to link an incoming pronoun to a potential antecedent, possible antecedents are supposed to be re-activated (Nicol & Swinney, 1989; MacDonald & MacWhinney, 1990). There is some ERP evidence that working memory is involved in the process of pronoun resolution. For example Streb and colleagues (1999) investigated the effects of pronoun and proper name anaphors in both parallel (easy) and non-parallel (difficult) syntactic discourse structures. A parallel structure means that pronoun and noun have the same syntactic function, and the establishment of the co-reference is relatively easy (such as in: "Peter visits Julia in the hospital. There he asked a question to the physician."). In contrast, in a non-parallel structure pronoun and antecedent have a different syntactic function, which is usually more difficult to interpret (such as in: "Peter visits Julia in the hospital. There she asked a question to the physician."). Streb and colleagues assumed that the nonparallel conditions involve more working memory load due to the higher degree of syntactic processing difficulty. They reported two ERP results: (1) Pronoun anaphors evoked a more pronounced negativity than proper name anaphors between 270 and 420 ms latency range over the frontal cortex electrodes. Another relative negativity occurred between 510 and 600 ms over the parietal sites. (2) *Anaphors in nonparallel positions compared to parallel positions were more negative over parietal sites.* The authors suggested that these two effects are functionally related to discourse resolution including a possible search in working memory for the suitable antecedent.

The aim of the present study was to investigate whether semantic integration, syntactic integration, or both interact with verbal working memory during establishing co-reference between a pronoun and the corresponding antecedent in sentences. In one condition a person was introduced as an antecedent and later referred to by a pronoun, which either agreed in biological/syntactic gender or not (biological/syntactic gender violation). In a second condition, a thing was introduced as an antecedent and the corresponding pronoun either agreed in syntactic gender with the antecedent or not (syntactic gender violation). To manipulate verbal working memory in pronoun processing the distance between antecedent and pronoun was either short (short distance = SD condition) or long (long distance = LD condition), see material in Table 5.1. This manipulation is in line with standard settings for

VWM manipulations (Daneman & Carpenter, 1980; King & Kutas, 1997). Increasing the distance between the pronoun and the antecedent demands more VWM capacity because possible antecedents have to be re-activated for further processing (Nicol & Swinney, 1989; van Berkum et al., 2003). While subjects read these eight different types of sentences their event-related potentials (ERP) were recorded. Following the logic of earlier ERP-research, we propose the following hypothesis: according to a strictly modular view, syntactic and semantic as well as working memory could work independently of each other. Following this, we expect an N400/P600 complex for double violations in the person sentence types, a P600 for syntactic violation in the thing sentence types, and we expect to find a LAN component for incongruent compared to congruent pronouns that is larger within the long distance conditions. Alternatively, according to a more interactive view, working memory could indirectly influence semantic and syntactic processing. In this case, we would expect a difference of the semantic and syntactic effect size of the N400 and/or P600 in the SD compared to the LD conditions:

Condition	Sentence
<i>SD P: Person as antecedent in short distance</i>	
C. congruent	Der Häuptling _{MALE/mas} ist kriegerisch, weil er _{MALE/mas} gewinnen will.
I. incongruent	Der Häuptling _{MALE/mas} ist kriegerisch, weil sie _{(FEMALE)/fem} gewinnen will.
<i>SD T: Thing as antecedent in short distance</i>	
C. congruent	Der Apfel _{mas} ist süß, weil er _{(MALE)/mas} reif ist.
I. incongruent	Der Apfel _{mas} ist süß, weil sie _{(FEMALE)/fem} reif ist.
<i>LD P: Person as antecedent in long distance</i>	
C. congruent	Der Häuptling _{MALE/mas} greift bald an und ist kriegerisch, weil er _{MALE/mas} gewinnen will.
I. incongruent	Der Häuptling _{MALE/mas} greift bald an und ist kriegerisch, weil sie _{(FEMALE)/fem} gewinnen will.
<i>LD T: Thing as antecedent in long distance</i>	
C. congruent	Der Apfel _{mas} ist sehr saftig und ist süß, weil er _{(MALE)/mas} reif ist.
I. incongruent	Der Apfel _{mas} ist sehr saftig und ist süß, weil sie _{(FEMALE)/fem} reif ist.

Table 5.1 Example Materials for the experiment. Translation: SD P: The chief is martial because he/she wants to win. SD T: The apple is sweet because he/she (it) is ripe. LD P: The chief attacks soon and is martial because he/she wants to win. LD T: The apple is very juicy and is sweet because he/she (it) is ripe. FEMALE/MALE = biological gender, mas = syntactic gender masculine, fem = syntactic gender feminine.

Figure 5.1 Grand average ERPs time locked to the onset of the Person-pronouns in SD sentences (upper panel) and LD sentences (lower panel) at a selected set of electrodes (negativity is up and each hash mark represents 200 ms of activity in this and in the following figures).

Short Distance

Long Distance

Figure 5.2 Grand average ERPs time locked to the onset of the Thing-pronouns in SD sentences (upper panel) and LD sentences (lower panel) at a selected set of electrodes.

5.4. Methods

Participants

Twenty German native speakers from the student population of the Maastricht University volunteered to take part in the experiment with written consent and were paid for their participation. All had normal or corrected-to-normal vision, were right-handed and neurologically healthy. Four datasets were not included in later analysis because of too many artifacts or technical problems, leaving data of sixteen participants (12 women, mean age 22 ± 2.2 years).

Material and design

For half of the material we used sentences from an earlier study (Hammer et al., 2005): Two-hundred-forty sentences, 120 about persons and 120 about things, had two clauses each. The first main clause described a state of a person or a thing. The person or the thing was the subject of the main clause, and formed the antecedent of the pronoun following later. Care was taken to guarantee equal word frequencies for persons and things using the CELEX-database (Baayen et al., 1995). The second clause was a subordinate clause introduced by the conjunction *weil* (*because*). This conjunction was followed by the critical word, a pronoun referring to the person or the thing. All sentences were then copied and the congruent pronoun was replaced by an incongruent pronoun. These sentences comprised the SD conditions of the current experiment. To manipulate verbal working memory (VWM) in pronoun processing the distance between antecedent and pronoun was increased by adding four words after the antecedent in the same sentences resulting in a total of 480 different sentences (see Table 5.1). Altogether this resulted in a $2 \times 2 \times 2$ design with VWM (SD/LD), antecedent type (person/thing P/T), and congruency (congruent/incongruent C/I) as factors. To minimize repetition the sentences were distributed across two different lists, counterbalancing antecedent type, congruency, and VWM. The sentences of each list were then pseudo-randomized over four blocks, in such a way that repetitions of antecedents were kept as far apart as possible. We measured eight subjects per list, which were pooled again for analysis. To ensure reading and sentence processing content related question were presented after 10 ± 5 sentences. Subjects were asked to answer the questions with 'yes' or 'no' by pushing one of two mouse buttons. This task was independent of the pronoun manipulation in order to avoid interference of the explicit task performance with the implicit electrophysiological measures. Only subjects with at least 80% correct answers in the comprehension task were accepted.

The words were presented white on black background in a 16-point font size (Arial) at a viewing distance of about 100 cm (subtending approximately 0.5 by 1.2 degrees of visual angle for critical words).

Procedure

Subjects were tested in a dimly lit sound-attenuating room while sitting in a comfortable chair. Subjects were asked to read the sentences concentrated and carefully because they were supposed to answer questions concerning the content of the sentences. They should fixate on the screen and avoid possible movements during the word-by-word presentation of the sentences. Between sentences and during the question subjects were free to blink and move their eyes.

A trial started with a fixation cross in the middle of the screen (duration 2050 ms) which was followed by the word-by-word presentation of the sentence. Each word was presented for 350 ms with a 250 ms inter-stimulus interval. Sentence ending words were presented with a dot indicating the end of a sentence, followed by a blank screen for 850 ms.

Questions were presented on the screen for 4 s. One block lasted approximately 20 minutes. The entire experiment, including instructions, electrode application, and removal took about 2.5 hours.

EEG recording and analysis

Electroencephalography (EEG) signals were registered with a digitization rate of 250 Hz and filtered with a band pass of 0.01-50 Hz. Twenty-nine tin electrodes mounted in an elastic cap were positioned according to the 10/20 system (Fz, Fcz, Afz, Cz, Cpz, Pz, Oz, F7/8, F3/4, C3/4, T3/4, T5/6, P3/4, O1/2, Fp1/2, Fc3/4, Tp7/8, Cp3/4). Bio-signals were recorded with a left mastoid reference, and were offline re-referenced to the mean of the activity at the two mastoids. Blinks and vertical eye-movements were recorded with electrodes placed at the sub- and supraorbital ridge of the left eye. Lateral eye-movements were monitored by a bipolar montage using two electrodes placed on the right and left external canthus. Eye movements were recorded in order to allow for later offline rejection. All electrode impedances (EEG and EOG) were kept below 5 k Ω .

From the continuous signal epochs were created of 1024 ms starting 100 ms prior to pronoun onset. These epochs were monitored for artifacts, such as eye-movements, by an automated procedure. Trials including artifacts were rejected from further analysis (10 % rejection on average, no difference between conditions). By averaging the remaining artifact-free epochs

per condition the Event-related potentials (ERPs) were derived. Waveforms were quantified by mean amplitude measures (relative to a 100 ms pre-stimulus baseline) to assess LAN/N400 (time window 200 to 400 ms) and P600 (400 to 700 ms) components. These windows were derived from previous pronoun experiments of our group and corroborated by visual inspection of the grand average ERPs. These measures were subjected to repeated measures analysis of variance that crossed the factors VWM (2; short vs. long, SL), Antecedent type (2; person vs. thing, PT), Congruency (2; congruent vs. incongruent, CI) and 'Electrode sites' (29 levels). Additionally, we compared the mean amplitudes of conditions in both time-windows by separate analyses for Congruency (SPC vs. SPI, LPC vs. LPI, and STC vs. STI, LTC vs. LTI) and VWM (SPC vs. LPC, SPI vs. LPI, and STC vs. LTC, STI vs. LTI) in order to trace back possible effects. Finally, ERPs were averaged for 2048 ms epochs with a 100-ms pre-stimulus interval in order to analyze the processing of the word following the pronoun. These measures were subjected to repeated analysis of variance following the same logic as above and an additional analysis for the frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal line (P3, Pz, P4) in a time window from 1000 to 1300 ms (corresponding to a 400-700 ms time-window for the word after the pronoun). The Greenhouse-Geisser correction for inhomogeneity of covariance was applied whenever an evaluated effect had more than one degree of freedom in the numerator.

5.2. Results

The grand average ERPs time-locked to the onset of the pronouns are shown in Figure 5.1 and 5.2 (comparing congruent and incongruent pronouns). Figure 5.1 shows the ERPs of pronouns referring to the person-antecedent within the SD conditions (upper panel) and within the LD conditions (lower panel). The ERPs of pronouns referring back to the thing antecedent can be seen in Figure 5.2 within SD condition (upper panel) and within LD condition (lower panel). All eight conditions elicit a N1-P2 complex, which is typical for visually presented material. In the SD-person condition, incongruent compared to congruent pronouns are characterized by a widespread negativity between 200 and 400 ms after pronoun onset. Past 400 ms the waveforms to incongruent and congruent pronouns are highly similar in the SD-person condition.

Source	df	F	P(GG)
Omnibus ANOVA (29 electrodes)			
VWM (short vs. long)	1, 15	5.58	.03
VWM x Electrode	28, 420	2.91	.03
VWM x Congruency x Electrode	28, 420	2.42	.04
Separate ANOVAs for Congruency (29 electrodes):			
SD P: Congruency (congruent vs. incongruent)	1, 15	6.40	.02
Congruency x El	28, 420	3.96	.002
SD T: Congruency (congruent vs. incongruent)	1, 15	0.09	
Congruency x El	28, 420	0.88	
LD P: Congruency (congruent vs. incongruent)	1, 15	0.20	
Congruency x El	28, 420	0.49	
LD T: Congruency (congruent vs. incongruent)	1, 15	0.02	
Congruency x El	28, 420	0.87	
Separate ANOVAs for Working Memory (29 electrodes):			
CP: VWM (short vs. long)	1, 15	9.52	.008
Mem x El	28, 420	3.25	.004
IP: VWM (short vs. long)	1, 15	0.01	
VWM x El	28, 420	1.46	
CT: VWM (short vs. long)	1, 15	2.06	
VWM x El	28, 420	1.93	.08
IT: VWM (short vs. long)	1, 15	2.28	
VWM x El	28, 420	0.56	

Table 5.2 Mean ERP amplitude ANOVAs in the 200 – 400 ms Latency Range. VWM, verbal working memory; El, Electrode; SD, short distance; LD, long distance; C, Congruent; I, Incongruent; P, Person; T, Thing; GG, Greenhouse Geisser corrected p-value for F tests with more than one degree of freedom. Table displays only ANOVA tests which are most relevant. All main effects that are not reported are not significant (NS). The same holds for the following table.

In contrast, the SD-thing condition does not show a difference in the 200 – 400 ms time window. Rather, from 400 ms after pronoun onset and extending well into the ERP of the next word, the ERP to incongruent stimuli is more positive than that to congruent SD-thing

pronouns. The LD conditions show a different ERP pattern. In both antecedent conditions in LD, the ERP waveforms are similar in the 200 – 400 ms time window. For person pronouns in LD, there is difference in the 400 – 700 ms range with incongruent pronouns being more positive than congruent pronouns whereas this effect is absent for LD thing pronouns.

Figure 5.3 and Figure 5.4 compare ERPs to pronouns for short and long distance sentences. For pronouns referring back to persons (Figure 5.3, upper panel) there is a difference in congruent pronouns with the LD condition being more negative than the SD condition between 200 and 700 ms. In contrast, incongruent person-pronouns (lower panel) show a difference in the P600 range (400 – 700 ms) with LD condition being more positive than SD. For thing-antecedents (Figure 5.4) a negativity for LD pronouns compared to SD pronouns is found between 200 and 450 ms for congruent (upper panel) and between 200 and 700 ms for incongruent pronouns (lower panel). The latter effect was seen mostly at parietal sites.

Statistical analysis is reported separately for the N400 and P600 latency range. Omnibus and separate ANOVAs are reported in Table 5.2 for the N400 range and in Table 5.3 for the P600 range.

Early negativity: 200 – 400 ms

Our pronoun manipulation showed a main effect for Working memory in an omnibus ANOVA (see Table 5.2) plus interactions of Working memory with Electrode, as well as with Congruency x Electrode. As can be seen in Figure 5.5 the interaction (Working memory x Congruency x Electrode) is mainly due to the fact that congruent and incongruent conditions differ in SD but not in LD memory sentences. Further analysis showed that this holds for the person sentences, and not for the thing sentences, as was confirmed by separate analyses (Table 5.2, Congruency) revealing a significant main effect for congruency for SD person sentences with incongruent pronouns being more negative than congruent pronouns. In contrast, separate analyses for SD thing sentences did not reveal a main effect for congruency, nor for person and thing LD conditions.

Separate ANOVAs comparing SD and LD sentences are reported in Table 5.2 as well (verbal working memory). Here, statistical analysis revealed a main effect for congruent person-pronouns with LD conditions being more negative than SD conditions. This effect was absent in all other conditions.

Congruent Person

Incongruent Person

Figure 5.3 Grand average ERPs time locked to the onset of Person-pronouns for congruent SD and LD sentences (upper panel) and incongruent SD and LD sentences (lower panel) at a selected set of electrodes.

Figure 5.4 Grand average ERPs time locked to the onset of Thing-pronouns for congruent SD and LD sentences (upper panel) and incongruent SD and LD sentences (lower panel) at a selected set of electrodes.

Figure 5.5 Mean amplitudes of the ERP waves for congruent and incongruent Person antecedents and for congruent and incongruent Thing antecedents during SD and LD pronoun resolution are demonstrated for the N400 (time-window 200-400 ms, left panel) and for the P600 (time-window 400 – 700, right panel).

P600: 400 – 700 ms

The omnibus ANOVA with 29 electrodes (Table 5.3) revealed a significant main effect for Congruency (congruent vs. incongruent), indicating a modulation of the P600 for our pronoun manipulation. Furthermore, we found a triple interaction Memory x Antecedent x Congruency, as well as an interaction between Memory and electrodes. As can be seen in Figure 5.5, this interaction is due to the fact that in the SD condition things but not persons are sensitive to a congruency manipulation. In contrast, in LD the opposite scenario is the case: persons but not things are sensitive to congruency. These effects were traced back by separate analyses (see Table 5.3, lower part) which revealed the following results: a main effect for congruency to thing pronouns in the SD conditions (incongruent more positive than congruent pronouns) and a main effect for congruency to person pronouns in the LD conditions (incongruent being more positive than congruent pronouns).

With respect to working memory effects statistical analysis revealed a main effect for congruent person-pronouns with LD conditions being more negative than SD conditions (see Figure 5.3). This seems to be a continuation of the negative effect reported above. As in the early time window, separate analyses for the other three conditions did not reveal any significant differences between LD and SD type sentences.

Source	df	F	P(GG)
Omnibus ANOVA (29 electrodes)			
Congruency (congruent vs. incongruent)	1, 15	8.07	.01
VWM x Antecedent x Congruency	1, 15	6.02	.03
VWM x EI	28, 420	4.34	.004
Separate ANOVAs for Congruency (29 electrodes):			
SD P: Congruency (congruent vs. incongruent)	1, 15	0.09	
Congruency x EI	28, 420	1.06	
SD T: Congruency (congruent vs. incongruent)	1, 15	4.79	.04
Congruency x EI	28, 420	1.77	
LD P: Congruency (congruent vs. incongruent)	1, 15	11.57	.004
Congruency x EI	28, 420	3.38	.047
LD T: Congruency (congruent vs. incongruent)	1, 15	0.52	
Congruency x EI	28, 420	0.65	
Separate ANOVAs for Working Memory (29 electrodes):			
CP: VWM (short vs. long)	1, 15	6.67	.02
VWM x EI	28, 420	3.71	.005
IP: VWM (short vs. long)	1, 15	1.36	
VWM x EI	28, 420	3.07	.009
CT: VWM (short vs. long)	1, 15	0.61	
VWM x EI	28, 420	1.46	
IT: VWM(short vs. long)	1, 15	3.03	
VWM x EI	28, 420	1.01	

Table 5.3 Mean ERP amplitude ANOVAs in the 400 – 700 ms Latency Range (P600). Note: VWM, verbal working memory; EI, Electrode; SD, short distance; LD, long distance; C, Congruent; I, Incongruent; P, Person; T, Thing; GG, Greenhouse Geisser corrected p-value for F tests with more than one degree of freedom.

Source	df	F	P(GG)
Omnibus ANOVA (29 electrodes)			
Congruency (congruent vs. incongruent)	1, 15	4.89	.04
Congruency x Electrode	28, 420	3.58	.006
VWM (short vs. long) x Electrode	28, 420	4.49	.008
Separate ANOVAs for Congruency (29 electrodes):			
SD P: Congruency (congruent vs. incongruent)	1, 15	0.28	
Congruency x El	28, 420	1.80	
SD T: Congruency (congruent vs. incongruent)	1, 15	3.61	.08
Congruency x El	28, 420	2.71	.04
LD P: Congruency (congruent vs. incongruent)	1, 15	0.17	
Congruency x El	28, 420	0.88	
LD T: Congruency (congruent vs. incongruent)	1, 15	2.68	
Congruency x El	28, 420	1.43	
Frontal (F3, Fz, F4) ANOVAs for Congruency (congruent vs. incongruent)			
SD P	1, 15	0.44	
SD T	1, 15	4.65	.047
LD P	1, 15	0.60	
LD T	1, 15	4.35	.05
Central (C3, Cz, C4) ANOVAs for Congruency (congruent vs. incongruent)			
SD P	1, 15	0.71	
SD T	1, 15	4.77	.045
LD P	1, 15	0.43	
LD T	1, 15	2.71	
Frontal (P3, Pz, P4) ANOVAs for Congruency (congruent vs. incongruent)			
SD P	1, 15	0.45	
SD T	1, 15	2.00	
LD P	1, 15	0.00	
LD T	1, 15	1.84	

Table 5.4 Mean ERP amplitude ANOVAs in the 1000 – 1300 ms Latency Range (late N400). Note: VWM, verbal working memory; El, Electrode; SD, short distance; LD, long distance; P, Person; T, Thing; GG, Greenhouse Geisser corrected p-value for F tests with more than one degree of freedom.

Figure 5.6 Grand average ERPs time locked to the onset of Person-pronouns (left) and Thing Pronouns (right) for SD conditions (Panel A) and for LD conditions (Panel B) at a selected set of electrodes.

Negativity at follow-up word: 1000-1300 ms

Figure 5.6 shows the grand average ERPs, time-locked to the onset of the pronoun up to the end of the following word for SD person and thing conditions (panel A) and LD person and thing conditions (panel B). In addition to the ERP-patterns described before Figure 5.6 shows a more negative waveform for the word following the pronoun ('reif') in incongruent sentences about things compared to congruent sentences in SD-conditions. This negativity begins approximately at 1000 ms and lasts up to 1300 ms (corresponding to 400-700 ms after word onset) with an anterior maximum. LD thing-conditions reveal a similar pattern with incongruent sentences being more negative than congruent sentences, but with a reduced effect size. However, these patterns are not visible for person sentences in SD and LD conditions.

Table 5.4 revealed that our pronoun manipulation in an omnibus ANOVA crossing factors Working memory, Antecedent, Congruency and Electrodes showed a significant main effect for Congruency and an interaction for Congruency x Electrode and VWM x Electrode in the 1000-1300 ms time window. Separate analysis splitting Person and Thing antecedents in SD and LD conditions revealed a main effect for congruency for SD thing-condition, indicating an N400 effect. Neither SD and LD person nor LD thing conditions reached significance.

Further topographical analysis showed that SD thing conditions reached significance at frontal and central sites. Moreover, LD thing conditions showed a trend towards a frontal negativity within the specified time-window.

5.3. Discussion

The aim of this experiment was to investigate the interaction of verbal working memory with semantic and/or syntactic information within the process of establishing co-reference between a pronoun and its antecedent. Previously, ERP effects suggestive of the involvement of syntactic information (P600; Osterhout & Mobley, 1995; Schmitt et al., 2002), semantic information (N400; King & Kutas, 1995) or both (N400/P600 complex; Schmitt et al., 2002) have been reported. Interactions of verbal working memory and semantic and/or syntactic information processing may be observed via differences of the N400 (semantic) and P600 (syntax) components between conditions with less demand on VWM (short distance) and more demand on VWM (long distance).

We applied a design that allowed us to study pure syntactic gender disagreement in comparison to combined semantic/syntactic violations (biological gender disagreement) using person or thing as antecedents. Additionally the present design allowed assessing the influence of different working memory demands on pronoun resolution. Such demands have been shown to give rise to a LAN component (Kluender & Kutas, 1993; Streb et al. 1999; van Berkum et al., 2003). While we did observe an enhanced negativity for LD relative to SD conditions with an onset latency of about 200 ms in three out of four conditions (congruent/incongruent thing, congruent person), these effects did not resemble a LAN component as they were rather widespread (Figures 5.3 and 5.4). At present, we are unable to determine a direct relationship of the negativities found between LD and SD conditions and the LAN reported in previous studies. We can only interpret the outcome based on our design assumptions. The only difference in the comparison is the distance between antecedent and pronoun. We therefore suggest that the observed negativity reflects the more difficult establishment of co-reference in a LD compared to a SD condition. The findings show that the system processes this difference within 200 ms after pronoun onset. We can only speculate on the meaning of this, but we think that this difference reflects a relatively easy conceptual reactivation of the antecedent in the SD compared to more difficult one in the LD condition.

The comparison of the ERPs to incongruent and congruent pronouns for the different conditions (Figures 5.1 and 5.2) allowed us to assess the influence of working memory demands on the N400 and P600 components elicited by the gender violations. Effects of working memory were found for both components, thus showing that VWM interacts with semantic and syntactic processing during the establishment of pronoun-antecedent co-reference.

Semantic integration and verbal working memory: As indicated in Figure 5.5 (left panel), we found an N400 effect for the SD Person condition only.² This finding can be interpreted such that VWM interacts with semantic gender information processing in sentences with person antecedents. In contrast, pronouns with thing sentence types did not show any N400 effect. This came as no surprise, as only syntactic gender processing was manipulated and therefore no semantic integration problems were involved for the violation conditions.

Why is there no N400 in the person LD condition? Figure 5.5 suggests that in LD condition the establishment of co-reference involving biological/semantic gender was so difficult that a ceiling effect was reached for the N400 effect: Semantic integration is not an all-or-none process (e.g. van Petten & Kutas, 1991). For example, a large N400 can be observed for sentence initial content words, in spite of the fact that these are perfectly sensible in that position. We propose that the LD manipulation raised semantic integration difficulty in the congruent person condition such that congruent and incongruent person conditions were indistinguishable for the N400 process. This idea is also supported by the observed negativity in the comparison of congruent LD/SD conditions (see previous page). In order to be able to link an incoming pronoun to a potential antecedent, possible antecedents are supposed to be re-activated (Nicol & Swinney, 1989; MacDonald & MacWhinney, 1990). We argue that this reactivation is probably more difficult for antecedents which are further away from the pronoun compared to close antecedents.

Syntactic integration and verbal working memory: As expected, we found a more positive ERP for incongruent compared to congruent pronouns for thing sentences in SD within the

² Why did we observe different outcomes for SD person sentences compared to the person sentences reported in Chapter 2? There, we reported a large P600 whereas here the very same material elicited an N400. One possible explanation would be that the comprehension system did react sensitive to the change in experimental set up. Adding more complex sentences (LD) to the experiment changed the assessment of difficulty for these sentence. Treating them as easier to solve compared to LD leads into a general difference in assessment for the same material evoking different processing as compared to singled presentation of these sentences.

400 – 700 ms time range. Furthermore, we found a P600 for person sentences in LD with incongruent pronouns being more positive than congruent. This is shown in Figure 5.5 (right panel). Additionally, there seems to be a P600 for thing sentences within the LD conditions, but this effect failed to reach significance. For the interpretation of this pattern of results we need to take into account current knowledge about the P600 effect. To reiterate the findings in the literature, an increase in P600 amplitude has been found in response to several kinds of syntactic violations such as subject-verb agreement violations (Hagoort et al. 1993; Osterhout & Mobley, 1995), verb inflection errors (Friederici et al. 1993; Gunter, Stowe & Mulder, 1997), case inflection errors (Münte et al., 1998a), and phrase structure violations (Friederici et al., 1999; Hahne & Friederici, 1999; Neville et al., 1991). In addition, P600 effects have been found for the less preferred structure in so-called ‘garden path’ sentences (e.g. *The woman persuaded to answer the door...*; Osterhout & Holcomb, 1992). Finally, Kaan, Harris, Gibson and Holcomb (2000) found P600 effects to grammatically correct, non-garden path sentences, which were hard to integrate. These results have led researchers to assume that the P600 amplitude is related to “syntactic processing difficulty” and that this phenomenon might be related to syntactic reanalysis (Osterhout et al., 1994; Rösler, Pechman, Streb, Röder & Hennighausen, 1998), syntactic integration difficulty (Kaan et al., 2000), or the inability to assign the preferred structure to the words encountered (i.e. Friederici et al., 1999). Such syntax-specific views are challenged by findings of a P600-like effect for rare semantic violations within long stories (Münte et al., 1998a), semantic reversal anomalies (*The cat that fled from the mouse ran across the room*. Kolk, Chwilla & van Herten, 2003), or semantic selectional restriction violations (*For breakfast the eggs would only eat ...*; Kuperberg, Holcomb, Sitnikova, Greve, Dale & Caplan, 2003).

Hagoort (2003) has recently provided an account of the processes underlying the P600 component drawing heavily from the ‘Unification model’, a computational model formulated by Vosse and Kempen (2000). The key concept of this model is that each word in the lexicon is associated with a structural frame that specifies the possible structural environment of this particular word. In the process of sentence comprehension, the syntactic frames are unified into a structural representation of the whole sentence by the formation of ‘unification links’. In Hagoort’s view, the amplitude of the P600 varies as a function of the difficulty of forming unification links. Factors determining the difficulty of this formation process include the presence of alternative unification options, syntactic complexity, as well as semantic influences. For example, expectancies about what is (im)possible in the real world, could hamper the formation of unification links, and thus produce a P600 effect, which would be

consistent with the various results indicating a P600 for semantic violations (Kolk et al., 2003; Kuperberg et al., 2003; Münte et al., 1998a).

Thus, sentence processing may underlie a hierarchical structure, and this should hold for building up co-reference between a pronoun and an antecedent as well. In case of a person antecedent within easy sentences the comprehension system relies on semantic gender information as reported above (N400 for incongruent compared to congruent SD person pronouns). In contrast, if only syntactic gender information is available as for pronouns referring back to thing antecedents in SD sentences, a P600 was observed indicating syntactic re-analysis. In case of more complex sentences, i.e. increased distance between pronoun and antecedent (LD conditions), the parser brings into play a different processing architecture. For LD person pronouns a direct index of semantic integration problems is absent (no N400) indicating a weaker reflex of independent semantic processing. Instead, the parser rather seems to rely on syntactic gender information indexed by a P600 component. Additionally, this P600 was larger for LD person pronouns compared to LD thing pronouns indicating more processing demands for building an unification link (Hagoort, 2003) based on increased distance and the violation of two types of gender information (biological and syntactic). In contrast, we did not observe a P600 for incongruent LD thing pronouns. Here, we speculate that the thing is not considered as the belonging antecedent to the pronoun due to the increased distance, at least not at pronoun position. Therefore, it might be fruitful to consider the observed effects on the word following the pronoun to take account of possible ongoing searching processes (Hammer et al., 2005). We found a late N400-like effect on the word following the pronoun within incongruent sentences about things compared to congruent. This effect was seen in SD and LD conditions (Figure 5.6). This effect was most salient at anterior sites. In contrast, no such pattern was found for SD or LD person sentences. This N400 has been shown to be sensitive to semantic integration (Kutas & Hillyard, 1980, 1983; Kutas & van Petten, 1994), as well as to discourse integration (St. George et al., 1999; Van Berkum et al., 1999). The observed effect therefore indicates an involvement of semantic (world knowledge of stereotypes) and/or discourse processing of words during the integration of the pronoun into the sentence. The anterior distribution of our N400-like effect could be related to the anterior negative effect for discourse-referential ambiguity reported by Van Berkum and colleagues (2003). This effect is consistent with the earlier finding of our group for the SD thing sentences (Hammer et al., 2005), which even holds for LD thing-conditions. Thus, the effect within thing sentences could be interpreted as an ongoing integration process in order to get the meaning of the pronoun right. This revision might be characterized by a searching

process for an alternative antecedent within the discourse. Therefore, the parser waits for new information in order to solve the incongruity, i.e. expecting a relation to an alternative antecedent in the discourse. The N400 occurs, if this process fails. In contrast, in the person-case, no N400 was found. Therefore, we can conclude that a revision does not take place at the word following the pronoun indicating that the integration process for these pronouns seems to be finished right after pronoun processing due to a reliable declining of bonding/resolution of pronoun and person-antecedent. This seems to be independent of the distance between pronoun and antecedent.

Conclusions

Thus, these data show that verbal working memory (VWM) and semantic and syntactic violation do interact. In a relatively less demanding VWM condition, the parser seems to have the preference to use semantic information to establish co-reference if this information is available, as in our person sentence types (biological gender information). It can distinguish between congruent and incongruent gender types (shown as a N400 and a lack of P600 in our SD person condition). If semantic gender information is not available (as for things in German), the syntactic parsing takes over because of its unambiguous syntactic information for German things (shown as the P600 in our SD thing condition). If there are more demands on VWM as in the LD conditions, the parser seems to rely on syntactic information rather than on semantic one (shown as a P600 and lack of N400 in the LD person condition). However, a high demand on VWM also interacts with pure syntactic parsing in such a way that a syntactic gender violation cannot be detected anymore (lack of P600 in our LD thing condition) at pronoun position. Furthermore, we found an anterior N400-like component on the word following the pronoun solely in Thing conditions, indicating an ongoing integration process for these conditions, which is independent of distance. In contrast, for Person-sentences the integration process is finished right after pronoun position, indexed by similar ERP waves on the word following the pronoun for incongruent and congruent sentences.

In general, these data suggest that sentence parsing is not only semantic or syntactic but rather a highly flexible process. Our different N400/P600 patterns suggest that a parser switches preference between semantic and syntactic information access during pronoun processing depending on demands on VWM resources and information availability.

Interaction of semantic and syntactic gender information and working memory during pronoun resolution: an fMRI study

Abstract

Personal pronouns are used to refer back to an earlier mentioned person or thing. In German, this re-reference can be based on syntactic and/or semantic gender information. The aim of this functional Magnetic Resonance imaging study was to localize syntactic and semantic information and possible interaction with verbal working memory (VWM) during the process of building up co-reference between a pronoun and its antecedent using the same material as in the study described in chapter five. We experimentally disentangled syntactic and biological/conceptual gender information by using German sentences either about a person (biological and syntactic gender assignment) or about a thing (syntactic gender assignment) followed by a congruent or incongruent pronoun in terms of gender. Additionally we manipulated VWM by increasing the distance across noun phrases between pronoun and antecedent resulting in a short distance (SD) and a long distance (LD) VWM condition. As a main result we found that left inferior frontal regions are the core region for building up co-reference between pronoun and antecedent with a slight local differentiation dependent on antecedent type. In addition, we suggest that left superior frontal regions may be ascribed as a general monitoring processor for clear gender violations within comparably easy sentences (SD) as we found deactivation for incongruent compared to congruent pronouns within these regions but not for LD sentences. Furthermore, possible search processes for alternative antecedents within LD thing sentences were reflected by activation of temporal and temporo-parietal regions. Furthermore, we demonstrated sensitivity to the distance manipulation depending on availability of gender information within congruent sentences, which was reflected in a temporal activation for LD compared to SD Person sentences, whereas for the thing case no temporal activation was found. For incongruent sentences we found a difference for antecedent types within temporal regions, with an anterior temporal activation for Person antecedents and a more posterior temporal activation for Thing antecedents. We suggested that these areas get active due to a search for an appropriate antecedent depending on information availability in case of violations, but also, in case of longer temporal distance (LD) between antecedents and pronouns.

6.1 Introduction

The present study focuses on patterns of brain activations associated with syntactic and semantic gender information processing and possible interactions with verbal working memory (VWM) during pronoun resolution. Reading a sentence like *'The woman is happy because she fell in love.'* it is easy to tell that 'she' refers back to the woman. In order to be able to integrate the pronoun 'she' into the sentence, it has to be re-referenced to the antecedent (i.e. the woman). Thus, the antecedent is supposed to be re-activated (Nicol & Swinney, 1989; MacDonald & MacWhinney, 1990) possibly by using VWM resources. Building up co-reference between pronoun and antecedent may be based on syntactic and/or biological/semantic gender information of the two. The woman in our example is characterized by female biological gender information. In German, this biological gender information is accompanied by feminine syntactic gender information (die_{feminine} Frau_{feminine/female}). In contrast, things are only characterized by (arbitrary) syntactic gender information without any semantic reflex (die_{feminine} Tasche_{feminine}). These characteristics of the German language enable us to systematically manipulate the process of syntactic and semantic gender information integration during pronoun processing. Now consider the sentence *'The woman was happy and kept on smiling because she fell in love.'* Here, the antecedent is further away from the pronoun. Therefore, the process of building up co-reference between the pronoun and belonging antecedent taxes more VWM resources because it either has to be kept available in VWM for a longer time or it has to be re-activated at a later time point compared to the shorter sentence. In addition to the processing of gender information, we focus on possible interaction of these with verbal working memory by varying the distance between pronoun and antecedent.

In chapter four, the reader finds an overview on recent investigations concerning imaging studies examining syntactic and semantic information processing (pp. 51-54), which will be summarized in the following. Syntactic processing was found to be located in an area of the left dorsolateral prefrontal cortex (Indefrey et al., 2001). Semantic processing revealed a more complex network including the bilateral inferior frontal and inferior-medial temporal cortex, left lateral frontal cortex, left posterior fusiform gyrus, bilateral motor cortex, and supplementary motor area (Kiehl et al., 2002). A more recent study revealed that the inferior prefrontal cortex is involved in integration of meaning (semantic) and world knowledge (Hagoort et al., 2004). Newman and colleagues (2001) investigated syntactic and semantic

processing within one study and reported that syntactic and semantic processing result in non-identical patterns of activation, including greater frontal engagement during syntactic processing and larger increases in temporal and temporo-parietal regions during semantic analyses. In a completely crossed design, Röder and colleagues (2002) varied syntactic processing demands (easy vs. difficult to process word order sequences) and the meaningfulness of sentences (real- vs. pseudo-word sentences). Semantic in contrast to pseudo-word sentences elicited a stronger activation in inferior frontal gyrus, and superior and middle temporal gyrus. Syntactic difficulty had its strongest effect within the left inferior frontal region and this effect was more pronounced for semantic than non-semantic speech. The authors interpreted their findings that semantic and syntactic language functions are mediated by partly specialized brain systems but that there is a substantial functional overlap of the involved brain structures, especially in left inferior frontal regions. Friederici and colleagues (2003) investigated brain areas supporting the processing of sentence-level semantic and syntactic information, finding that both processes are supported by a temporo-frontal network with distinct areas specialized for semantic (mid-portion of the superior temporal region bilaterally and the insular cortex bilaterally) and syntactic processes (anterior portion of the left superior temporal gyrus, the left posterior frontal operculum (adjacent to Broca's area) and the putamen in the left basal ganglia).

Imaging studies on Working Memory (WM): Cooke and colleagues (2001) investigated the where of syntactic working memory with fMRI by presenting sentences differing in grammatical structure (subject- vs. object-relative) and their short-term memory demands (short vs. long antecedent-gap linkages). Subjects were asked to consider whether a male or a female person performed an action. There were two main results. First, the right posterior superior temporal cortex showed activation during processing of long distance antecedent-gap without any grammatical influence in comparison to a pseudofont baseline. The authors took this finding as this area supports passive short-term memory during sentence comprehension. Second, the left inferior frontal cortex was associated with sentences that featured both an object-relative clause and a long antecedent-gap in comparison to the baseline. This suggests that this region supports the cognitive resources required to maintain long-distance syntactic dependencies during comprehension of grammatically complex sentences. Fiebach, Schlesewsky, and Friederici (2001) found comparable results for German short and long wh-questions differing in their grammatical function (subject vs. object wh-question).

Martin and Chao (2001) presented a review on semantic memory. They concluded based on i.e. Damasio's work (1996) that the temporal lobe object representation system is organized hierarchically, with increasing convergence and integration of information (from generic to unique) occurring along its posterior to anterior axis. Furthermore, they stated that evidence has accumulated suggesting that an anterior and inferior prefrontal region (roughly equivalent to BA47 and the inferior aspect of BA45) may be involved selectively in semantic processing. Specifically, as suggested by Gabrieli, Poldrack, and Desmond (1998) and Wagner (1992), this region may serve as a 'semantic working memory system' responsible for retrieving, maintaining and manipulating semantic representation stored elsewhere.

In a more recent study, Thierry, Ibarrola, Démonet, and Cardebat (2003) investigated the involvement of the inferior prefrontal cortex in VWM (which is the subsystem for working memory devoted to verbal information (Baddely, 1998)). Subjects listened to pairs of French words. Half of the presented words corresponded to artifacts, the other half to natural things. Each semantic group featured an equal number of feminine and masculine nouns. Subjects' task was to monitor the pairs for a category. Within a pair, both words pertained to a specific category (feminine, masculine, natural, artificial). First, the authors could vary VWM demands by manipulating the number of verbal items (one or two), which needed to be categorized. Either it was possible to make a decision without processing the second word (release condition) or the second word had to be held in VWM in order to respond (hold condition). Second, two different language tasks were used, a gender decision (syntax categorization into feminine and masculine) and a semantic decision (categorization into artificial and natural). Therefore, the authors claimed to test whether VWM would interact with the linguistic process in focus. The authors reported the following main results: (1) Reaction times were faster in release than hold conditions with gender decision being faster than semantic decisions. (2) Activation patterns were remarkably similar across tasks and conditions, revealing a wide bilateral network, i.e. including the superior temporal gyrus, inferior prefrontal gyrus, thalami, and lingual gyri. The authors concluded that the performed cognitive operations (in particular access to meaning of the words) were too similar to allow different networks to be involved. (3) A significant hemodynamic peak delay between hold and release condition was identified in the inferior prefrontal regions but not in superior temporal regions, and this effect did not interact with the language task. This finding indicated that superior frontal regions showed no sensitivity to a condition change, whereas the major factor influencing the time course of the inferior prefrontal cortex hemodynamic response was verbal working memory rather than the linguistic task in question.

To summarize the above studies, we look for common findings between them. Syntactic processing was dominantly located in prefrontal regions (Indefrey et al., 2001; Newman et al., 2001; Röder et al., 2002 and Friederici et al., 2003). In addition, Friederici and colleagues (2003) reported an activation of the anterior portion of the left superior temporal gyrus and the putamen for syntactic processing. However, semantic processing was dominantly located within inferior frontal regions (Kiehl et al., 2002; Newman et al., 2001; Röder et al., 2002; Friederici et al., 2003 [insular cortex]; and Hagoort et al., 2004) and superior and/or middle temporal regions (Kiehl et al., 2002; Newman et al., 2001; Röder et al., 2002; Friederici et al., 2003). With respect to syntactic WM (i.e. maintaining long distance syntactic dependencies) the involvement of the left inferior frontal cortex was reported (Cooke et al., 2001, Fiebach et al., 2001), as well as for a 'semantic WM system' (Gabrieli et al., 1998; for a review see Martin and Chao, 2001). However, temporal lobe was titled as an object representation system (Damasio, 1996). This was supported by the work of Thierry and colleagues (2003), who reported similar activation patterns for semantic and syntactic processing, including the superior temporal gyrus, inferior prefrontal gyrus as well. In addition, they reported that a higher demand on WM delays the time course of the inferior prefrontal cortex hemodynamic response, whereas the superior temporal gyrus was insensitive to this effect.

The aim of the present fMRI study was to localize corresponding neuronal areas to semantic integration and syntactic integration and whether they would interact with verbal working memory during establishing co-reference between a pronoun and the corresponding antecedent in sentences. We used a passive reading task in a standard violation paradigm to avoid effects of explicit cognitive decision tasks. Our paradigm allows us to investigate syntactic and semantic information processing based on the gender type of the antecedent. In one condition a person was introduced as an antecedent and later referred to by a pronoun, which either agreed in biological/syntactic gender or not (biological/syntactic gender violation). In a second condition, a thing was introduced as an antecedent and the corresponding pronoun either agreed in syntactic gender with the antecedent or not (syntactic gender violation). In addition, we manipulated verbal working memory (WM) in pronoun processing for both linguistic conditions by increasing the distance between antecedent and pronoun. Thus, the distance was either short (short distance = SD condition) or long (long distance = LD condition, see Table 6.1 for example material).

Condition	Sentence
SD P: Person as antecedent	
C. congruent	Der Häuptling _{MALE/mas} ist kriegerisch, weil er _{MALE/mas} gewinnen will.
I. incongruent	Der Häuptling _{MALE/mas} ist kriegerisch, weil sie _{FEMALE/fem} gewinnen will.
SD T: Thing as antecedent	
C. congruent	Der Apfel _{mas} ist süß, weil er _{(MALE)/mas} reif ist.
I. incongruent	Der Apfel _{mas} ist süß, weil sie _{(FEMALE)/fem} reif ist.
LD P: Person as antecedent	
C. congruent	Der Häuptling _{MALE/mas} greift bald an und ist kriegerisch, weil er _{MALE/mas} gewinnen will.
I. incongruent	Der Häuptling _{MALE/mas} greift bald an und ist kriegerisch, weil sie _{FEMALE/fem} gewinnen will.
LD T: Thing as antecedent	
C. congruent	Der Apfel _{mas} ist sehr saftig und ist süß, weil er _{(MALE)/mas} reif ist.
I. incongruent	Der Apfel _{mas} ist sehr saftig und ist süß, weil sie _{(FEMALE)/fem} reif ist.

Table 6.1 Example Materials for the experiment Translation: SD P: The chief is martial because he/she wants to win. SD T: The apple is sweet because he/she (it) is ripe. LD P: The chief attacks soon and is martial because he/she wants to win. LD T: The apple is very juicy and is sweet because he/she (it) is ripe. FEMALE/MALE = biological gender, mas = syntactic gender masculine, fem = syntactic gender feminine.

In the rest of this chapter, a contrast comparing incongruent to congruent sentences will be labeled as Congruency contrast (incongruent minus congruent sentences), and a contrast comparing LD to SD sentences will be labeled as VWM contrast (LD minus SD sentences). Following the logic of earlier research as reported above, we propose the subsequent hypothesis: For the comparatively simple SD sentences, we expect an increase of Blood oxygen level-dependent (BOLD) response within the left inferior frontal (IF) regions for Congruency, specifically in BA47/45. In contrast, we expect the more complex LD sentences to lead to an increase of BOLD response in a more complex activation pattern for Congruency, viz. left inferior frontal and temporal regions (i.e. the superior temporal gyrus) because these sentences tax more verbal working memory resources. Splitting up these comparisons into the two different antecedent types, we aimed to take further insights into syntactic and semantic/syntactic gender information processing during pronoun resolution. The direct comparison of LD and SD conditions should reveal regions specialized for VWM. Co-reference is supposed to be more difficult for LD compared to SD sentences and may therefore lead to an increase of BOLD response in frontal regions for the VWM contrast. In addition, we expect the involvement of temporal regions (Thierry et al. 2003; Martin and Chao, 2001). More specifically, following Martin and Chao (2001), there should be a

difference for Person compared to Thing conditions. For the VWM contrast for congruent and/or incongruent Person-sentence, we supposed to find an enlarged BOLD response in anterior regions of the temporal lobe, whereas VWM contrast for congruent and/or incongruent Thing-sentence should lead to an increase in BOLD response in more posterior regions.

6.2 Methods

Subjects

Six German native speakers (three females, mean age 24 ± 3.4) volunteered to take part in the experiment with written consent and were paid for their participation. All had normal vision, were right-handed and neurological healthy.

Measurements

Functional measurement: BOLD dependent functional magnetic resonance images were obtained using a 3 Tesla Siemens Magnetom Trio Vision system (Siemens, Erlangen), with echo planar imaging capabilities and a radiofrequency (RF) head (8-)coil (gradient echo EPI, TR = 2 s, TE = 30 ms, FOV = $220 \times 220 \text{ mm}^2$, flip angle = 80° , matrix size = 64×64 , in-plane resolution $3.4375 \times 3.4375 \text{ mm}^2$, slice thickness = 3.5 mm, interslice gap 0.35, 30 slices oriented parallel to the AC-PC-line, specified with a midsagittal scout image). One functional run consisted of 550 volumes. In order to avoid a T1 saturation effect we did not present any material during the first 7 volumes and excluded the first four volumes from further analyses.

Anatomical measurement: A high-resolution anatomical image was acquired (MP-RAGE, T₁-weighted, gradient-echo pulse sequence, TR = 1800 ms, TE = 3.44 ms, flip angle = 7° , FOV = 256 mm, matrix size = 256×256 , 192 sagittal slices, in-plane resolution $1 \times 1 \text{ mm}^2$, slice thickness = 1 mm).

Material and design

Eight types of sentences were presented to the subjects as summarized in Table 6.1. We used 64 sentences per condition of the material used in the experiment described in chapter five. Each sentence had two clauses. The first clause in each sentence was the main clause, which described a state of a person or a thing. The person or the thing was the subject of the main clause, and formed the antecedent of the pronoun following later. Care was taken to guarantee equal word frequencies for persons and things using the CELEX-database (Baayen et al.,

1995). The second clause was a subordinate clause introduced by the conjunction *weil* (*because*). This conjunction was followed by the critical word, a pronoun referring to the person or the thing. All sentences were then copied and the congruent pronoun was replaced by an incongruent pronoun. The just described sentences were the Short Distance (SD) conditions in this experiment. To manipulate VWM in pronoun processing the distance between antecedent and pronoun was increased by adding four words after the antecedent in the given sentences resulting in 512 different sentences in total. Altogether this resulted in a $2 \times 2 \times 2$ design with VWM (Short Distance/Long Distance SD/LD), antecedent type (person/thing P/T), and congruency (congruent/incongruent C/I) as factors. To minimize repetition, the sentences were distributed across two different lists, counterbalancing antecedent type, congruency, and VWM. Sentences on a list were then pseudo-randomized over four blocks (eight sentences per condition in one run), in such a way that repetitions of antecedents were kept apart as far as possible. We measured three subjects per list. They were pooled again later for analysis.

Procedure

Subjects were asked to read the sentences concentrated and carefully, as if they were supposed to answer questions concerning the content of the sentences. They should fixate on the screen and avoid possible movements during scanning. Before subjects entered the scanner's room they performed a training sequence, in which they read seven sentences similar to the experimental ones. Words were white and presented on black background.

The beginning of a trial was the first word of a sentence, which was time-triggered to the sixth main trigger of the scanner following the preceding sentence-trial, thus always starting with a volume scan. In between sentences, an asterisk was presented as fixation point. Thus, the experiment was a slow event-related design, allowing the BOLD response to settle down to baseline in between trials (i.e. sentences in this case). We employed a word-by-word presentation in order to avoid eye-movements associated with free-field sentence reading and to monitor sentence-processing time more carefully. Each word was presented for 350 ms with a 250 ms inter-stimulus interval. A word with a period was the sentences ending word.

Each scanning session started with a scout imaging for position information. Right after that, two functional scans (550 volumes, 64 sentences, eight sentences per condition) were performed followed by the structural scan allowing subjects to rest. After this break, the remaining two functional runs were performed.

Image analysis

Image analysis was performed using BrainVoyager QX software. For analysis all images were corrected for motion artifacts, corrected for slice-scan time order, temporally smoothed based on a linear trend removal procedure using an high pass filter of 3 cycles per time-point, co-registered with the subjects' corresponding anatomical (T1-weighted) images, normalized into standard coordinate system (Talairach and Tournoux, 1988), and spatially smoothed using a 4 mm full-width-at-half-maximum Gaussian kernel. Furthermore, surface rendering, and cortex reconstruction were performed.

For multiple regression analysis of the functional data, a general linear model (GLM) with predictors for (1) general conditions (SD congruent; SD incongruent; LD congruent and LD incongruent including person and thing antecedents) and for (2) each experimental condition (separating person and thing antecedents) was computed. Using contrast (t) maps, significant differences between conditions were assessed. Multiple comparisons were controlled by the False Discovery Rate (FDR) approach at a level of $q=0.05$ (Genovese et al., 2002), operating simultaneously on all voxelwise test statistics to determine which tests should be considered statistically significant, and controlling the expected proportion of the rejected hypotheses that are falsely rejected. Reported activations are based on a fixed effects group statistics.

In order to increase the sensitivity of statistical analysis, an improved alignment of the brains was achieved by inter-subject alignment procedure. A polygon mesh of each cortical hemisphere was obtained by segmenting and tessellating the white/grey matter boundary (Dale & Sereno, 1993; Fischl et al., 1999; Kriegeskorte & Goebel, 2001). Then, cortical time-courses were created by sampling the functional time-series at positions corresponding to the nodes of the cortical mesh. Polygon meshes (and corresponding cortical time-courses) were morphed into alignment using spherical representations of the cortical sheet (Fischl, Sereno, Tootell & Dale, 1999). This procedure provides accurate matching of morphologically homologous cortical locations among subjects while minimizing metric distortion. Again, for multiple regression analysis of the functional data, a general linear model (GLM) approach with predictors for each experimental condition was computed. Using contrast (t) maps, significant differences between conditions were assessed. For thresholding, the equivalent t-values to the FDR analysis were chosen. We display our averaged functional activation on the hemispheres of one subject, the target brain for the surface-based morphing procedure. This allowed viewing functional activity in relation to sulcal and gyral folds.

Figure 6.1

(A) Congruency effect for SD sentences (contrast: incongruent minus congruent person and thing sentences). ROIs: left inferior frontal gyrus (GFs) and superior frontal gyrus (GFs). (B) Congruency effect for LD sentences (contrast: incongruent minus congruent person and thing sentences). ROIs: left GFs, inferior frontal sulcus (SFi), superior temporal gyrus (GTs) and supramarginal gyrus (Gsm). 1 Activated voxels as revealed by across subject ($n=6$) analysis (GLM) after cortex-based inter subject alignment based on gyral/sulcal pattern of individual brains for the respective specified effect 2 Event-related average time course of the BOLD response for the regions of interest. 3 Responses to the specified contrast in regions of interest as reflected in the linear-regression standardized b weights (β estimates) averaged across subjects. Black bars represent congruent sentences and white bars represent incongruent sentences. Error bars indicate the standard errors of the average b weights.

Figure 6.2 Congruency effect (contrast: incongruent minus incongruent sentences) for (A) SD Person sentences, ROIs: left inferior frontal sulcus (SF1) and superior frontal gyrus (GFs). (B) SD Thing sentences, ROIs: SF1 and GFs. (C) LD Person sentences, ROIs: left SF1, pars triangularis (PT) and insula (Ins). (D) LD Thing sentences, ROIs: GFs, inferior frontal gyrus (GF1), superior temporal gyrus (GFs) and angular gyrus (Ga). **1** Activated voxels as revealed by across subject ($n=6$) analysis (GLM) after cortex-based inter subject alignment based on gyral/sulcal pattern of individual brains for the respective specified effect **2** Event-related average time course of the BOLD response for the regions of interest. **3** Responses to the specified contrast in regions of interest as reflected in the linear-regression standardized b weights (β estimates) averaged across subjects. Black bars represent congruent sentences and white bars represent incongruent sentences. Error bars indicate the standard errors of the average b weights.

6.3 Results

Congruency

For the SD conditions, we found an enlarged BOLD response for incongruent pronouns compared to congruent pronouns for pooled Person and Thing sentences within left inferior frontal gyrus (GFi). Additionally, there was an enlarged decrease of BOLD response for incongruent compared to congruent pronouns within the left superior frontal gyrus (GFs) (see Figure 6.1, panel A1). Panel 2 and 3 show the event-related time-course and corresponding beta-weights to the respective region of interest (ROI) within this and the following figures. Table 6.2 reports detailed statistical information to the ROIs.

Panel B of Figure 6.1 shows the results of the comparison of the more complex LD-conditions (Person and Things antecedents are pooled). Here, we observed a more complex left-sided activation pattern for incongruent compared to congruent pronoun, including GFi, inferior frontal sulcus (SFi), superior temporal gyrus (GTs) and supramarginal gyrus (Gsm). Figure

Figure 6.3 Enlarged view on the core region, the inferior frontal sulcus superimposing all congruency contrasts (incongruent minus congruent). Activations are identical to the activations shown in Figure 6.2. Blue represents short distance Person, green short distance Thing, red long distance Person and magenta long distance Thing.

6.2 shows the results to the separate analysis for person and thing antecedents. Here again, for the short distance conditions, we find an enlarged BOLD response for incongruent compared to congruent pronouns within the left SFi for person (panel A) and thing (panel B) antecedents. There is a larger decrease in BOLD response for incongruent compared to congruent pronouns within left GFs for both antecedent types as well. On a first glance, these findings indicate that person and thing conditions do not differ within easy to process sentences. However, Figure 6.3 indicates that observed activations of the given contrasts to SD person conditions are located more anterior compared to SD thing conditions.

Figure 6.4 (A) Verbal working memory effect for congruent sentences (contrast: LD minus SD person and thing sentences). ROIs: left and right superior frontal gyrus (GFs), supramarginal/angular gyrus (Gsm/a), temporal pole (TP) and superior temporal sulcus (STs). (B) Verbal working memory effect for incongruent sentences (contrast: LD minus SD person and thing sentences). ROIs: left GFs, left and right TP and superior temporal gyrus (GTs). **1** Activated voxels as revealed by across subject ($n=6$) analysis (GLM) after cortex-based inter subject alignment based on gyral/sulcal pattern of individual brains for the respective specified effect **2** Event-related average time course of the BOLD response for the regions of interest. **3** Responses to the specified contrast in regions of interest as reflected in the linear-regression standardized b weights (β estimates) averaged across subjects. Black bars represent SD sentences and white bars represent LD sentences. Error bars indicate the standard errors of the average b weights.

In contrast, within the long distance conditions the two antecedent types differ from each other in their activation patterns. For the LD person condition (Figure 6.2, panel C), we find a larger BOLD response within the inferior frontal sulcus (SFi), pars triangularis (PT) and the insula (Ins) at the left hemisphere. In contrast, LD thing conditions (panel D) revealed enlarged BOLD response at GFs, GF_i, angular gyrus (Ga) and superior temporal sulcus (STs) at the left hemisphere, indicating a complex pattern of pronoun processing for more complex sentence types, viz. long distance conditions. Table 6.3 reports detailed statistical information to the ROIs.

Name of ROI	BA	Size Nr. of voxel	Talairach			Contrast	
			x	y	z	t	p
SD (i - c)							
1. GF _i , LH	44/48	406	-42	14	27	4.8	.00002
2. GFs, LH	9	1180	-16	38	43	-5.7	.000001
LD (i - c)							
1. GF _i /SFi LH	44/48	2250	-41	19	19	5.7	.000001
2. GTs, LH	22/48	1008	-52	-15	2	5.8	.000001
3. Gsm, LH	21/22/41	1576	-46	-47	20	6.3	.000001
Congruent (LD - SD)							
1. GFs, LH	8/9	3294	-23	28	44	-7.8	.000001
2. Gsm/a, LH	39/40/48	5413	-47	-47	33	-6.3	.000001
3. TP, LH	38	340	-47	17	-16	3.6	.0003
4. STs, LH	48/21	231	-44	-27	3	3.0	.002
5. GFs, RH	8/9	627	32	21	48	-6.5	.000001
6. Gsm/a, RH	39/40	1131	50	-51	38	-5.6	.000001
7. TP, RH	38	716	44	13	-21	6.1	.000001
8. STs, RH	48/22/21	449	51	-20	-2	4.4	.00001
incongruent (LD - SD)							
1. GFs, LH	6	491	-37	0	47	5.1	.000001
2. TP, LH	38/21	1062	-47	11	-17	5.0	.00001
3. GTs, LH	22/21	1455	-56	-26	6	5.0	.00001
4. TP, RH	38	1151	46	12	-19	6.6	.000001
5. GTs, RH	48/22/21	746	49	-18	-4	5.7	.000001

Table 6.2 ROI details for main effects. Activated areas from the fMRI experiment. All regions reported are listed here and provided with presumed Brodman areas (BA); voxel size; Talairach coordinates as defined by Talairach and Tournoux (1998; x: left-right; y: anterior-posterior origin in anterior commissure; z: inferior-superior) and statistic values for specific contrasts (t, p). Abbreviations: LH: left hemisphere; RH: right hemisphere; GF_i, inferior frontal gyrus; GFs: superior frontal sulcus; SFi: inferior frontal sulcus; GTs: superior temporal gyrus; Gsm: supramarginal gyrus; Ga: angular gyrus; TP: temporal pole; STs: superior temporal sulcus.

Figure 6.5 (A) Verbal working memory effect for congruent Person sentences (contrast: LD minus SD sentences). ROIs: left and right superior frontal gyrus (GFs), supramarginal/angular gyrus (Gsm/a), temporal pole (TP) and right medial temporal gyrus (GTm). (B) Verbal working memory effect for incongruent Person sentences (contrast: LD minus SD sentences). ROIs: left and right TP and superior temporal sulcus (STs). 1 Activated voxels as revealed by across subject ($n=6$) analysis (GLM) after cortex-based inter subject alignment based on gyral/sulcal pattern of individual brains for the respective specified effect 2 Event-related average time course of the BOLD response for the regions of interest. 3 Responses to the specified contrast in regions of interest as reflected in the linear-regression standardized b weights (B estimates) averaged across subjects. Black bars represent SD sentences and white bars represent LD sentences. Error bars indicate the standard errors of the average b weights.

Figure 6.6 (A) Verbal working memory effect for congruent Thing sentences (contrast: LD minus SD sentences). ROIs: left and right superior frontal gyrus (GFs), left angular gyrus (Ga) and right temporal pole (TP). (B) Verbal working memory effect for incongruent Thing sentences (contrast: LD minus SD sentences). ROIs: left GFs and superior temporal gyrus (GTs) and right TP and medial temporal sulcus (STm). 1 Activated voxels as revealed by across subject ($n=6$) analysis (GLM) after cortex-based inter subject alignment based on gyral/sulcal pattern of individual brains for the respective specified effect 2 Event-related average time course of the BOLD response for the regions of interest. 3 Responses to the specified contrast in regions of interest as reflected in the linear-regression standardized b weights (β estimates) averaged across subjects. Black bars represent SD sentences and white bars represent LD sentences. Error bars indicate the standard errors of the average b weights.

Name of ROI	BA	Size Nr. of voxel	Talairach			Contrast	
			x	y	z	t	p
SD Person (i > c)							
1. SFi, LH	48/44	109	-43	15	25	3.5	.0005
2. GFs, LH	9/8	740	-17	38	50	-4.7	.000003
SD Thing (i > c)							
1. SFi, LH	48/45	46	-47	23	20	4.3	.000001
2. GFs, LH	9	1032	-27	40	38	-5.0	.00002
LD Person (i > c)							
1. SFi, LH	45/46	87	-42	43	5	4.2	.00003
2. PT, LH	45/48	263	-44	22	12	4.1	.00004
3. Ins, LH	48	168	-29	16	-1	4.2	.00003
LD Thing (i > c)							
1. GFs, LH	32	955	-10	27	50	5.2	.000001
2. GFi, LH	48	537	-41	12	30	4.6	.000004
3. GTs, LH	48	226	-48	-12	-1	3.9	.0001
4. Ga, LH	41/21	923	-45	-46	20	4.7	.000002
Congruent Person (LD > SD)							
1. GFs, LH	8/9	1265	-22	24	46	-5.3	.000001
2. Gsm/a, LH	39/48	5233	-45	-50	32	-5.3	.000001
3. TP, LH	38	100	-48	18	-15	3.6	.0003
4. GFs, RH	9/8	661	36	21	45	-4.3	.00001
5. Gsm/a, RH	39	1276	49	-52	35	-4.2	.00002
6. TP, RH	38/21	274	44	11	-20	4.0	.00007
7. GTm, RH	48/22	698	49	-17	-5	3.8	.0001
Incongruent Person (LD > SD)							
1. TP, LH	38	380	-44	15	-21	4.5	.000008
2. STs, LH	22/48	367	-54	-25	5	4.2	.00002
3. TP, RH	38/21	666	47	11	-19	5.5	.000001
5. STs, RH	48	798	49	-17	-4	4.8	.000002
Congruent Thing (LD > SD)							
1. GFs, LH	9/8	1763	-23	30	43	-5.7	.000001
2. Ga, LH	39/40	890	-49	-49	36	-3.9	.00009
3. GFs, RH	8/9	201	33	23	48	-4.5	.000006
4. TP, RH	38	241	42	12	-25	4.9	.000001
Incongruent Thing (LD > SD)							
1. GTs, LH	22	204	-60	-33	10	4.4	.00002
2. GFs, LH	9	1015	-8	44	42	4.2	.00002
3. TP, RH	38	498	43	14	-20	5.5	.000001
4. STm, RH	21/20	176	49	-5	-20	5.0	.000001

Table 6.3 ROI details for Person and Thing. Activated areas from the fMRI experiment. All regions reported are listed here and provided with presumed Brodman areas (BA); voxel size; Talairach coordinates as defined by Talairach and Tournoux (1998; x: left-right; y: anterior-posterior origin in anterior commissure; z: inferior-superior) and statistic values for specific contrasts (t, p). Abbreviations: LH: left hemisphere; RH: right hemisphere; SFi: inferior frontal sulcus; GFs: superior frontal sulcus; PT: pars triangularis; Ins: insula; GFi, inferior frontal gyrus; GTs: superior temporal gyrus; Ga: angular gyrus; Gsm: supramarginal gyrus; TP: temporal pole; GTm: medial temporal gyrus; STs: superior temporal sulcus; STm: medial temporal sulcus.

Verbal Working Memory

Comparing the congruent comparative complex sentences (LD) to the congruent relative easy sentences (SD) (Figure 6.4, panel A), we found a bilateral activation pattern including four different areas. Within left and right temporal pole (TP) and superior temporal sulcus (STs), congruent LD sentences revealed an enlarged increase in BOLD response compared to congruent SD sentences. In contrast, with the GFs and supramarginal/angular gyrus (Gsm/a) we found the opposite direction of the effect; congruent LD sentences showed an enlarged decrease of BOLD response compared to congruent SD sentences.

Interestingly, comparing incongruent LD to SD conditions (Panel B) we find a different activation pattern, including the left GFs and bilaterally TP and GTs. In addition, there seemed to be a delay of hemodynamic response for incongruent LD sentences compared to incongruent SD sentences in left temporal regions (panel B2).

Now, separating person and thing antecedents for the VWM contrasts, we found the following results for Person (Figure 6.5) and for Thing antecedents (Figure 6.6). Comparing congruent LD to SD conditions of Person antecedents (panel A), we found an enlarged increase of BOLD response for bilateral TP and the right medial temporal gyrus (GTm). Here as well, there was an enlarged decrease of the hemodynamic function in bilateral GFs and Gsm/a for congruent LD compared to SD sentences. In contrast, incongruent Person (panel B) antecedents revealed an increase of BOLD response for LD compared to SD conditions within bilateral temporal regions, viz. TP and STs.

Comparing congruent LD to SD sentences about thing antecedents (Figure 6.6, panel A), we found an enlarged decrease of hemodynamic response at bilateral GFs and left Ga, and a larger increase of hemodynamic response at right TP. In contrast, incongruent thing sentences (panel B1) revealed an increase of BOLD response at left GFs and GTs, and right STm and TP for LD compared to SD sentences. For this contrast no difference in the event-related BOLD response was observed (panel B2).

6.4 Discussion

The aim of this study was to investigate the involvement of semantic/biological and syntactic gender information processing and possible interaction with verbal working memory during the process of building up co-reference between a pronoun and person- or thing antecedents in German. Persons are characterized by semantic/biological and accompanying syntactic gender

information. Thus, a pronoun referring back to a person may be re-referenced by biological and/or syntactic gender information. In contrast, in German things are only characterized by an (arbitrary) syntactic gender information and so building up co-reference between pronoun and thing may solely be based on syntactic gender information. To manipulate verbal working memory, we increased the distance between antecedent and pronoun. First, we discuss the findings to Short- and Long Distance conditions for congruent and incongruent pronouns and then specify these in more detail by means of Person- and Thing antecedents (Congruency effects). Later on, we focus on verbal working memory by comparing congruent LD with SD sentences and incongruent LD with SD sentences and specify these as well in more detail by means of Person- and Thing antecedents.

Congruency

For incongruent compared to congruent sentences within easy to solve SD sentences we found an enlarged BOLD signal change within the left GF_i, indicating that the left GF_i is the core region for syntactic and semantic gender information processing during the process of building up co-reference between a pronoun and belonging antecedent. The activation of GF_i is in accordance with earlier studies which report the involvement of that region for syntactic and semantic information processing (Newman et al., 2001, Röder et al., 2002, Friederici, 2003). Surprisingly, we found significantly less activation for incongruent compared to congruent conditions in left superior frontal regions (blue colored areas in Figure 6.1). Looking into the time course of the BOLD signal change, we see an enlarged decrease of BOLD signal change for incongruent compared to congruent SD sentences in these regions. What does a negative BOLD response mean? Stefanovic, Warnking and Pike (2004) described the negative BOLD response as a marker of neuronal deactivation, defined as the hemodynamic down regulation accompanying neuronal inhibition. According to this, our enlarged decrease of BOLD response of incongruent compared to congruent SD sentences suggest a neuronal inhibition within superior frontal areas due to the clear and easy to detect violation of the pronoun's gender information. Noticing that the pronoun cannot be re-referenced to the close antecedent, the comprehension system suppresses further integration attempts indicating a general monitoring role of the left GFs. These frontal areas suggest involvement of short term memory in this process. In contrast, the more difficult to process LD condition revealed a different activation pattern for incongruent compared to congruent sentences. Here, we found a left sided activation of inferior frontal regions including GF_i and SF_i, superior temporal regions (SF_i) and the supramarginal gyrus. This complex activation

pattern suggests that building up co-reference over a longer distance is a different process compared to the SD scenario. In contrast to the SD condition, the LD congruency contrast lacks in prefrontal activation and shows instead a salient left temporal lobe activation. This might reflect an access to long-term memory (temporal regions) instead of a search/access to VWM (more frontally).

Splitting the SD and LD congruency effects into Person and Thing antecedents, we achieved comparable results for the SD sentences for both antecedent types, confirming the key role of GF_i in building up co-reference during the process of pronoun resolution based on syntactic and semantic gender information. However, within LD sentences the two antecedent types differed from each other in their activation patterns. As we solely found an enlarged BOLD signal change in left inferior frontal regions (SF_i, PT and Ins) for incongruent compared to congruent person sentences we concluded that biological gender accompanied with syntactic gender information processing in complex sentences is processed via or within these regions. In contrast, for LD thing sentences (pure syntactic gender information processing in more difficult sentences) we observed a complex activation pattern on the left hemisphere for incongruent compared to congruent thing sentences including superior and inferior frontal regions (GF_s and GF_i) and the angular gyrus. It seems that LD thing sentences are the most difficult to process sentences within this experiment. The comprehension system can only use syntactic gender information to create coherence between pronoun and antecedent. Possibly, the antecedent has been processed such a long time ago that there seems to be no attempt to integrate the incongruent pronoun into the sentence. Instead, there seems to be a search for an alternative antecedent (i.e. a person as potential actor outside the sentence context) indexed by activation of brain regions usually referenced to semantic information processing, viz. the Gsm. This process of searching for an antecedent outside the thing-sentence context is supported by previous event-related potentials data from our own group. The thing-sentence condition elicited a negative effect, the N400 with incongruent being more negative than congruent, on the word following the pronoun, as reported by Hammer and colleagues (2005, chapter 2 this volume). For the LD person case, we did not find an indication to this external semantic search in temporal long-term memory related cortical regions, as solely frontal regions were activated. Here, it seems that two types of gender information – biological and syntactic – create a strong coherence between pronoun and antecedent resulting in a successful refusal of the incongruent pronoun. Figure 6.3 showed the engagement of the key region, viz. GF_i, for all congruency contrasts. Even though there is a certain amount of overlapping regions, it seems that person antecedents are located more anteriorly compared to

thing antecedents. This finding is in accordance with results by Röder and colleagues (2002), who reported an interaction of syntactic and semantic processing within left inferior frontal regions. But it also suggests further specifications of the GF_i for the processing of different types of antecedents or actors in a sentence.

Verbal Working Memory

A direct measure of VWM was realized by comparing LD to SD sentences. This was done for congruent and incongruent sentences separately – first pooling Person and Thing antecedents and afterwards separating both antecedent types.

For the pooled approach we found enlarged BOLD signal change for congruent LD sentences compared to SD sentences within bilateral temporal pole (TP) and superior temporal sulcus (STs) and additionally an unexpected decreased BOLD signal change for congruent LD to SD sentences in GFs and Gsm/a on both hemispheres. The activation of temporal regions for congruent LD compared to SD sentences indicates that the access to antecedents requires more processing capacity within temporal regions in cases of higher distance between pronoun and antecedent, where an ‘object representation system’ is supposed to be stored (Damasio, 1996; Thierry et al., 2003). In contrast, the decreased BOLD signal change within bilateral GFs and Gsm/a for LD compared to SD sentences containing congruent pronouns remains speculative. Granted the assumption that a decreased BOLD response reflects a neuronal inhibition, these regions were deactivated for congruent LD compared to SD sentences, eventually by processes that are sensitive to detect distances between words, i.e. integrate words into sentence and discourse context over time. On the other hand, as expected, we do find increased activation for congruent LD sentences compared to SD sentences in temporal regions indicating access to the temporal semantic working memory system (Martin & Chao, 2001) in order to re-activate the distant antecedent. Separating congruent sentences into Person and Things antecedents, we found that the described results solely apply to Person sentences. In contrast, for congruent Thing sentences, we found a different activation pattern, with a larger increase of BOLD signal change at right TP and an enlarged decrease at bilateral GFs and left Ga for LD compared to SD sentences. This finding indicates that for pronoun resolution within congruent sentences the neural comprehension system is sensitive to the antecedent in combination with VWM manipulation, reflected in a temporal activation for LD compared to SD Person sentences (biological and syntactic gender information), whereas for the thing case (solely syntactic gender information) no temporal activation was found.

Now, comparing incongruent LD to SD sentences we found left-sided activation of the GFs, and a bilateral activation for TP and GTs. In more detail, we found a delayed event-related time-course for LD compared to SD sentences within left temporal regions. In general, the localization of the activation pattern is congruent with the findings by Thierry and colleagues (2003). Turning to incongruent comparisons, Person sentences revealed an increase of BOLD signal change for LD compared to SD conditions within bilateral anterior temporal regions (TP and STs), whereas Thing sentences revealed an increase of BOLD response at left posterior regions (GFs and GTs) and right anterior temporal regions (STm and TP) for LD compared to SD sentences. These findings indicate that temporal regions are sensitive to our experimental manipulation with respect to the type of antecedent of the pronoun, resulting in an anterior temporal activation for Person antecedents and left-sided more posterior temporal activation for Thing antecedents. This is in congruency with the semantic working memory network that was described by Martin and Chao (2001). The authors stated that posterior temporal regions seem to be associated with more general representations, whereas anterior temporal regions are related to more specific representations, i.e. famous faces. We suggest that these areas get active due to a search for an appropriate antecedent in case of violations, but also in case of longer temporal distance between antecedent and pronoun (as in our LD conditions).

Conclusions

The presented results revealed that building up co-reference between pronoun and antecedent within sentences depends on the distance between pronoun and antecedent in addition to the availability of gender information of the antecedent (syntactic or biological/syntactic). If an incoming pronoun cannot be integrated into a sentence due to an incongruent syntactic or biological type of gender information, left inferior frontal regions become more activated compared to congruent pronouns independent of the distance between pronoun and antecedent. Zooming into that core region showed that sentences about a person are processed more anteriorly compared to sentences about things indicating that this region differentiates between person and thing antecedents during pronoun processing. In addition, if the pronoun is close to the person or thing antecedents as in SD sentences, left superior frontal regions seemed to inhibit further integration attempts, indicated by a decrease of the hemodynamic response function. Thus, a general monitoring processor is in these superior frontal areas, which inhibits further integration attempts in case of close and clear gender violations for both types of antecedents. With an increased distance between antecedent and pronoun (LD

sentences), this inhibition process was absent. Instead, we observed an additional activation within temporal and temporo-parietal regions for LD thing sentences containing an incongruent compared to a congruent pronoun. The comprehension system can only use syntactic gender information to link the pronoun to the antecedent. Thus, there seems to be a search for an alternative antecedent (i.e. a person as potential actor outside the sentence context) indexed by an activation of brain regions usually referenced to semantic information processing, viz. the Gsm. Furthermore, the neural comprehension system is sensitive to the distance between pronoun and antecedent depending on availability of gender information within congruent sentences, which was reflected in a temporal activation for LD compared to SD Person sentences (biological and syntactic gender information). In contrast, for the thing case (solely syntactic gender information) no temporal activation was found. For incongruent sentences we found a difference for antecedent types within temporal regions, with an anterior temporal activation for Person antecedents and left-sided more posterior temporal activation for Thing antecedents. We suggest that these areas get active due to a search for an appropriate antecedent depending on information availability in case of violations, but also, in case of longer temporal distance between antecedents and pronouns as in our LD case.

Summary / Samenvatting

Summary

A multi-method approach was used to explore the cognitive processes of pronoun resolution within sentences in six different experiments. German pronouns (*er*_{MALE/masculine}, *sie*_{FEMALE/feminine}) that refer to a person are determined by the biological gender (MALE/FEMALE) and/or syntactic gender (masculine/feminine) of the person. Pronouns (*er*_{masculine}, *sie*_{feminine}) that refer to a thing are determined by its arbitrary syntactic gender (Garten (garden)_{masculine}, Tasche (hand-bag)_{feminine}). We presented sentences in word-by-word reading paradigms with either a person or a thing as antecedent, which were followed by a congruent or incongruent pronoun. Hereby, it was of interest to investigate whether semantic and/or syntactic integration are involved in establishing coreference between a pronoun and an antecedent by means of gender information violation. In addition, we increased the distance between pronoun and antecedent to elucidate whether syntactic and/or semantic pronoun resolution would interact with verbal working memory (VWM). By using different methods, we were able to investigate the time-course (when) of investigated processes (event related potentials, ERP) and the localization (where) of respective neuronal networks (functional magnetic resonance imaging, fMRI).

The review of literature given in **Chapter 1** shows present knowledge about the involvement of syntactic and semantic information processing for establishing co-reference between a pronoun and a suitable antecedent and the influence of extra processing due to increased difficulty in sentences. Altogether, the review lead to three important ERP components, namely the N400 (semantic integration problems), the P600 (syntactic processing difficulty and reanalysis) and the left anterior negativity (LAN, working memory). Neuroimaging studies detected a complex neuronal network for language comprehension including i.e. inferior frontal regions, superior and middle temporal regions, and regions adjacent to the supramarginal/angular gyrus.

In **Chapter 2** we present ERP findings which show that violations are reflected in the P600 in pure syntactic gender violation (things) and in combination of syntactic and biological gender violation (persons) at pronoun position. This effect was larger for the person compared to the thing condition suggesting that the P600 is sensitive to the availability of semantic gender information of the antecedent (here, whether or not it has biological gender). Furthermore, the observed N400 for the word following the pronoun in case of thing but not

person antecedent types indicated that this effect reflects continuous integration processes for things, whereas for persons the integration seems to be finished at pronoun position.

Surprisingly, contrary to the clear results of the first experiment, simultaneously recorded magnetoencephalographic data failed to reveal reliable differences between incongruent and congruent pronouns referring back to person or thing antecedents as reported in **Chapter 3**. This result is discussed as demonstrating different outcomes for ERP and event related fields (ERF) data due to different characteristics of the two methods, i.e. measuring tangential vs. radial sources or widely distributed sources for higher cognitive processes. When higher processing stages, such as language processing are the interest of investigation, the corresponding sources may be widely distributed and currents flowing simultaneously in opposing walls of a sulcus may partially cancel each other out. In that case, ERP might prove to be the more valuable source of information.

To localize the underlying neuronal networks of biological and syntactic gender integration during pronoun processing, we performed an event-related fMRI study, described in **Chapter 4**. Overall, syntactic processing activated left hemispheric areas adjacent to Broca's area and superior temporal sulcus (STs), whereas processing of the biological gender information, in addition, involved a bilateral network including inferior frontal gyrus (GFi) and the supramarginal gyrus (Gsm). A comparison with ERPs elicited with identical material (experiment 1 in chapter 2) suggested that the information is integrated 400-700 ms after target onset, visible in both cases as a P600 with different effect sizes. The results illuminate temporal and spatial integration of syntactic and semantic processing during the establishment of co-reference between a pronoun and its referring noun. Pronouns referring back to persons can be matched to the antecedent by biological and syntactic information, requesting more processing capacity indicated by the large P600 and the activation of a bilateral cortical network, including GFi and Gsm/Ga. In contrast, pronouns referring back to things are solely matched by pure syntactic gender information reflected in a smaller P600 indicating less processing activity and an activation of the left GFi and STs.

Integrating a pronoun into a sentence context requires VWM resources because the earlier mentioned antecedent has to be re-activated to link the pronoun to the antecedent. In the experiment described in **Chapter 5** we manipulated this process by increasing the distance (long distance conditions, LD) across person and thing sentences and compared these to the

sentences of the former experiments (short distance conditions, SD) within an ERP experiment. In general, this VWM manipulation effected the N400/P600 patterns of our sentence types, indicating that VWM interacts with semantic and syntactic processing. Furthermore, our data suggest that sentence parsing does not only depend on semantic or syntactic information but it is rather a highly flexible process. The respective N400/P600 patterns suggested that the comprehension system switches preference between semantic and syntactic information access during pronoun processing depending on demands on VWM resources and information availability. In addition, we found an N400 on the word following the pronoun for SD and LD thing sentences, indicating an ongoing integration process after pronoun position, independent of distance manipulation.

The aim of the fMRI study reported in **Chapter 6** was to localize processing of syntactic and semantic gender information and possible interaction with VWM during the process of building up co-reference between a pronoun and its antecedent, using the material as described in chapter five. As a main result, we found that left inferior frontal regions are the core regions for building up co-reference between pronoun and antecedent, with a slight local differentiation dependent on antecedent type. In addition, we suggest that left superior frontal regions may be described as a general monitoring processor for clear gender violations within relatively easy SD sentences, as we found deactivation for incongruent compared to congruent pronouns within these regions, but not for LD sentences. Instead, we observed additional activation within temporal and temporo-parietal regions if the comprehension system can only rely on syntactic gender information to link the pronoun to a distant antecedent (LD thing). The search for an alternative antecedent was indexed by activation of brain regions usually referenced to semantic information processing, viz. the Gsm. Furthermore, we demonstrated sensitivity to the distance manipulation, depending on availability of gender information within congruent sentences, which was reflected in a temporal activation for LD compared to SD person sentences, whereas for the thing case no temporal activation was found. For incongruent sentences we found an anterior temporal activation for Person antecedents and a more posterior temporal activation for thing antecedents. We suggest that these areas get active due to a search for an appropriate antecedent, depending on information availability in case of violations, but also in case of longer temporal distance (LD) between antecedents and pronouns.

Samenvatting

In zes verschillende experimenten werd een multi-methodebenadering gebruikt om de cognitieve verwerkingsprocessen van pronomen binnen zinnen te onderzoeken. Duitse pronomen die naar een persoon verwijzen ($er_{\text{MAN/mannelijk}}$, $sie_{\text{VROUW/vrouwelijk}}$) worden bepaald door het biologische geslacht (MAN/VROUW) en/of het syntactische geslacht van de persoon (mannelijk/vrouwelijk). Pronomen die naar een ding verwijzen ($er_{\text{mannelijk}}$, $sie_{\text{vrouwelijk}}$) worden bepaald door hun willekeurig syntactische geslacht ($\text{Garten (tuin)}_{\text{mannelijk}}$, $\text{Tasche (handtas)}_{\text{vrouwelijk}}$). In woord-voor-woord lees paradigma's boden wij zinnen aan met een persoon of een ding als antecedent die door een congruent of incongruent pronoom werden gevolgd. Hierbij was het van belang te onderzoeken of de semantische en/of syntactische integratie betrokken is bij het maken van een coreferentie tussen een pronoom en zijn antecedent door middel van een schending van de geslachtsinformatie. Bovendien verhoogden wij de afstand tussen het pronoom en het antecedent om te onderzoeken of de syntactische en/of semantische verwerking van pronomen met het verbaal werkgeheugen (verbal working memory, VWM) in wisselwerking zou staan. Door verschillende methodes te gebruiken, konden wij het tijdsverloop (wanneer) van onderzochte processen (event related potentials, ERP) en de lokalisatie (waar) van respectieve neuronale netwerken (functioneel magnetische resonantie imaging, fMRI) onderzoeken.

Het literatuur overzicht dat in **Hoofdstuk 1** wordt gegeven toont de huidige kennis over de betrokkenheid van syntactische en semantische informatieverwerking bij het vestigen van een coreferentie tussen een pronoom en een geschikt antecedent. Tevens werd genoemd dat de invloed van extra verwerking toe te schrijven is aan de verhoogde moeilijkheid in zinnen. Alles bij elkaar leidt het overzicht tot drie belangrijke ERP componenten, namelijk de N400 (semantische integratieproblemen), de P600 (her-analyse en moeilijkheidsgraad van syntactische verwerking) en de 'left anterior negativity' (LAN, het werkgeheugen). Neuroimaging onderzoeken ontdekten een complex neuronale netwerk voor taalbegrip met inbegrip van o.a. inferieure frontale gebieden, superieure en mediale temporale gebieden, en gebieden naast de supramarginale/angulaire gyrus.

In **Hoofdstuk 2** tonen wij ERP bevindingen, welke aantoonen dat de schendingen bij zuivere syntactische geslachtsschending (dingen) en bij de combinatie van syntactische en biologische geslachtsschending (personen) op de positie van het pronoom in een P600 worden

weerspiegeld. Dit effect was groter voor de persoon-conditie dan voor de ding-conditie, wat suggereert dat de P600 gevoelig is voor de beschikbaarheid van semantische geslachtsinformatie van het antecedent (hier, het al dan niet hebben van een biologisch geslacht). Verder wees de waargenomen N400 voor het woord direct na het pronoom, in het geval van ding maar niet persoon antecedent types, erop dat dit effect continue integratieprocessen voor ding-conditions weerspiegelt, terwijl voor persoon-conditions de integratie bij de positie van het pronoom lijkt te zijn beëindigd.

In **Hoofdstuk 3** wordt gerapporteerd dat, in tegenstelling tot de duidelijke resultaten van het eerste experiment, gelijktijdig geregistreerde MEG (magnetoencephalographic) gegevens, verrassend genoeg geen betrouwbare verschillen lieten zien tussen congruente en incongruente pronomen die naar persoon- of ding-antecedenten terugverwijzen. Dit resultaat wordt verklaard door de verschillende resultaten voor ERP en event related fields (ERF) gegevens, toe te schrijven aan de verschillende kenmerken van de twee methodes (o.a. het meten van divergerende versus radiale bronnen of de ruimtelijke verspreiding van de bronnen voor hogere cognitieve processen). Wanneer de hogere verwerkingsstadia de kern van het onderzoek zijn, zoals bij taalverwerking het geval is, dan kunnen de relevante bronnen ruimtelijk verspreid zijn en kunnen stromen elkaar gedeeltelijk compenseren wanneer die gelijktijdig optreden op tegenover liggende kanten van een sulcus. In dat geval zou kunnen blijken dat ERP de waardevollere bron van informatie is.

Om de onderliggende neuronale netwerken van biologische en syntactische geslachtsintegratie tijdens pronomen verwerking te lokaliseren, voerden wij een event related fMRI experiment uit, dat in **Hoofdstuk 4** wordt beschreven. In het algemeen activeert syntactische verwerking gebieden in de linker hemisfeer die naast het gebied van Broca liggen en de superieure temporale sulcus (STs), terwijl de verwerking van de biologische geslachtsinformatie tevens een bilateraal netwerk met inbegrip van inferieure frontale gyrus (GFi) en supramarginale gyrus (Gsm) omvatte. Een vergelijking met ERPs waarbij identiek materiaal werd gebruikt (experiment 1 in hoofdstuk 2), toonde aan dat de informatie 400-700 ms na aanvang van de stimulus geïntegreerd wordt, in beide gevallen duidelijk waarneembaar als een P600 met verschillende effect grootte. De resultaten belichten temporele en ruimtelijke integratie van syntactische en semantische verwerking tijdens de totstandbrenging van coreferentie tussen een pronoom en zijn verwijzend zelfstandig naamwoord. Voor pronomen die terugverwijzen naar personen kan het passende antecedent door middel van biologische en

syntactische informatie gevonden worden. Waarbij meer verwerkingscapaciteit nodig is, wat zichtbaar is in een grote P600 en de activering van een bilateraal corticaal netwerk, met inbegrip van GF_i en Gsm/GA. Het passende antecedent voor pronomen die naar dingen terugverwijzen kan daarentegen alleen door de zuivere syntactische geslachtsinformatie gevonden worden. Dit is zichtbaar in een kleine P600 en wijst op minder verwerkingsactiviteit en een activering van linker GF_i en STs.

Het integreren van een pronom in een zinscontext vereist het inzetten van het VWM, omdat het eerder vermelde antecedent moet worden gereactiveerd om het pronom met het antecedent te verbinden. In het experiment beschreven in **Hoofdstuk 5** manipuleerden wij dit proces door de afstand bij persoon-zinnen en ding-zinnen te verhogen (long distance conditions, LD) en we vergeleken deze met de zinnen van de voorgaande experimenten (short distance conditions, SD) binnen één ERP experiment. In het algemeen beïnvloedde deze manipulatie van het VWM, de N400/P600 patronen van onze zinstypes waaruit blijkt dat het VWM betrokken is bij semantische en syntactische verwerking. Tevens wijzen onze gegevens er op dat de zinsontleding niet alleen van semantische of syntactische informatie afhangt, maar dat het eerder een hoogst flexibel proces is. De eerder vermelde N400/P600 patronen wijzen er op dat het begripssysteem tijdens de verwerking van pronomen, schakelt tussen voorkeur voor semantische en syntactische informatie, afhankelijk van belasting van het VWM en beschikbaarheid van informatie. Bovendien vonden wij een N400 op het woord na het pronom voor SD en LD ding-zinnen, wat wijst op een integratieproces dat doorgaat na de positie van het pronom, onafhankelijk van de afstandsmanipulatie.

Het doel van de fMRI studie die in **Hoofdstuk 6** wordt vermeld, was het lokaliseren van de verwerking van syntactische en semantische geslachtsinformatie en de mogelijke interactie met het VWM tijdens het proces dat coreferentie tussen een pronom en zijn antecedent opbouwt. Bij dat onderzoek werd gebruik gemaakt van het materiaal dat in hoofdstuk vijf wordt beschreven. Als hoofdresultaat vonden wij dat de linker inferieure frontale gebieden het kerngebied zijn voor het opbouwen van een coreferentie tussen pronom en antecedent met een lichte lokale differentiatie afhankelijk van antecedent type. Bovendien stellen wij dat de linker superieure frontale gebieden beschouwd kunnen worden als een algemene controlerende verwerkingseenheid voor duidelijke geslachtsschendingen binnen relatief gemakkelijke SD zinnen, aangezien wij binnen deze gebieden een deactivering voor incongruente pronomen vonden in vergelijking met congruente pronomen, maar dit niet

vonden voor de LD zinnen. In plaats daarvan zagen wij extra activering binnen temporale en temporoparietale gebieden, als het begripssysteem zich slechts op syntactische geslachtsinformatie kan baseren om het pronoom met een ver antecedent (het LD ding) te verbinden. Het zoeken naar alternatieve antecedenten werd geïndiceerd door een activering van hersengebieden die gewoonlijk aan semantische informatieverwerking van verwijzingen worden toegeschreven, namelijk Gsm. Bovendien toonden wij aan dat de gevoeligheid van de afstandsmanipulatie afhankelijk is van de beschikbaarheid van geslachtsinformatie binnen overeenstemmende zinnen, wat in een activering van temporele gebieden voor LD in vergelijking met de zinnen van de persoon van SD werd weerspiegeld, terwijl in het geval van een ding geen activering van temporele gebieden werd gevonden. Voor incongruente zinnen vonden wij voorafgaand aan de activering van temporele gebieden, voor de antecedenten van de persoon en een meer latere activering van temporele gebieden voor de antecedenten van het ding. Wij stellen dat deze gebieden geactiveerd worden vanwege het zoeken naar het passende antecedent, afhankelijk van informatiebeschikbaarheid in het geval van schendingen, maar ook in het geval van een langere temporele afstand (LD) tussen antecedenten en pronomen.

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Appendices

Appendix I

Materials for Chapter 2 (experiment 1), Chapter 3, and 4

A: Person as antecedent:

1. Die Frau ist beliebt, weil sie/er hübsch ist.
2. Die Nonne ist fromm, weil sie/er gläubig ist.
3. Die Tante ist akkurat, weil sie/er Ordnung mag.
4. Die Oma liest gern, weil sie/er Geschichten mag.
5. Die Prinzessin war munter, weil sie/er Schlaf bekam.
6. Die Tochter ist krank, weil sie/er angesteckt wurde.
7. Die Nichte ist allein, weil sie/er oft umzog.
8. Die Schülerin hat geschwänzt, weil sie/er faul war.
9. Die Dame ist traurig, weil sie/er einsam ist.
10. Die Hexe ist aufgeregt, weil sie/er Besuch hat.
11. Die Witwe muss weinen, weil sie/er traurig ist.
12. Die Beamtin ist gestresst, weil sie/er Kinder hat.
13. Die Studentin ist nervös, weil sie/er Prüfungen hat.
14. Die Baronin ist glücklich, weil sie/er bald heiratet.
15. Die Ballerina schreibt Autogramme, weil sie/er berühmt ist.
16. Die Freundin backt Kuchen, weil sie/er Geburtstag hat.
17. Die Sekretärin ist verärgert, weil sie/er Überstunden macht.
18. Die Königin ist beliebt, weil sie/er gut ist.
19. Die Ärztin ist klug, weil sie/er gelernt hat.
20. Die Braut ist zittrig, weil sie/er aufgeregt ist.
21. Die Chefin ist verzweifelt, weil sie/er betrogen wurde.
22. Die Diva ist stur, weil sie/er hochnäsiger ist.
23. Die Dozentin ist streng, weil sie/er viel fordert.
24. Die Enkelin ist niedlich, weil sie/er klein ist.
25. Die Spielerin ist arm, weil sie/er viel verliert.
26. Die Patientin ist besorgt, weil sie/er krank ist.
27. Die Sängerin ist fröhlich, weil sie/er viel singt.
28. Die Schneiderin ist froh, weil sie/er Stoff kaufte.
29. Die Schwester ist wütend, weil sie/er geärgert wird.
30. Die Stewardess ist arbeitslos, weil sie/er Flugangst bekam.
31. Die Zigeunerin ist beweglich, weil sie/er viel tanzt.
32. Die Zeugin ist ängstlich, weil sie/er bedroht wird.
33. Die Erzieherin ist müde, weil sie/er viel arbeitet.
34. Die Gattin ist sparsam, weil sie/er arm ist.
35. Die Journalistin ist verreist, weil sie/er Entspannung sucht.
36. Die Professorin ist anwesend, weil sie/er Besprechungen hat.
37. Die Rentnerin ist wach, weil sie/er Kaffee trank.
38. Die Sklavin ist hungrig, weil sie/er wenig isst.
39. Die Schwedin ist musikalisch, weil sie/er Klavier spielt.
40. Die Konkurrentin ist schroff, weil sie/er benachteiligt wurde.
41. Die Pflegerin ist geduldig, weil sie/er warten kann.
42. Die Forscherin ist wissbegierig, weil sie/er interessiert ist.
43. Die Kundin ist modisch, weil sie/er gefallen möchte.
44. Die Lehrerin unterrichtet gut, weil sie/er spontan ist.
45. Die Kandidatin ist betrübt, weil sie/er schwanger wurde.
46. Die Kameradin war böse, weil sie/er zuhause blieb.
47. Die Jungfer wird ignoriert, weil sie/er klein ist.

48. Die Irin ist spontan, weil sie/er verreisen möchte.
49. Die Kauffrau ist verschuldet, weil sie/er unaufmerksam war.
50. Die Kellnerin ist unsicher, weil sie/er heute beginnt.
51. Die Köchin ist verschwitzt, weil sie/er viel arbeitet.
52. Die Greisin ist weise, weil sie/er alt ist.
53. Die Heldin erlebt Abenteuer, weil sie/er mutig ist.
54. Die Magd hat frei, weil sie/er Urlaub hat.
55. Die Blondine wollte schwimmen, weil sie/er Wasser mag.
56. Die Kaiserin ist ideenreich, weil sie/er kreativ ist.
57. Die Arbeiterin ist eingestellt, weil sie/er zuverlässig ist.
58. Die Polin ist verlobt, weil sie/er verliebt ist.
59. Die Gouvernante kauft Kleider, weil sie/er eitel ist.
60. Die Göttin wird verehrt, weil sie/er großzügig ist.

61. Der Engländer ist errötet, weil er/sie schüchtern ist.
62. Der Abiturient ist schnell, weil er/sie laufen kann.
63. Der Polizist wirkt autoritär, weil er/sie Uniformen trägt.
64. Der Arzt ist überarbeitet, weil er/sie Patienten betreut.
65. Der Herr ist reich, weil er/sie geizig ist.
66. Der Schauspieler ist erfolgreich, weil er/sie ehrgeizig ist.
67. Der Schlosser ist schmutzig, weil er/sie viel arbeitet.
68. Der Vater ist ungeduldig, weil er/sie Ruhe braucht.
69. Der Ingenieur ist unerfahren, weil er/sie jung ist.
70. Der Fahrer ist gefährlich, weil er/sie getrunken hat.
71. Der Sänger ist bekannt, weil er/sie fantastisch singt.
72. Der Patient hustet viel, weil er/sie zuviel raucht.
73. Der Dichter ist poetisch, weil er/sie Gedichte schreibt.
74. Der Pianist ist einsam, weil er/sie viel reist.
75. Der Spieler ist enttäuscht, weil er/sie verloren hat.
76. Der Bengel ist langsam, weil er/sie verletzt ist.
77. Der König ist mächtig, weil er/sie reich ist.
78. Der Bruder ist sportlich, weil er/sie viel trainiert.
79. Der Soldat ist kräftig, weil er/sie Fitness betreibt.
80. Der Anwalt schläft schlecht, weil er/sie beunruhigt ist.
81. Der Pirat ist betrunken, weil er/sie heute feiert.
82. Der Rentner ist draußen, weil er/sie gern wandert.
83. Der Richter ist verreist, weil er/sie Termine hat.
84. Der Ritter ist verletzt, weil er/sie gekämpft hat.
85. Der Professor ist beschäftigt, weil er/sie Arbeit hat.
86. Der Fischer ist beruhigt, weil er/sie angeln kann.
87. Der Geselle ist unachtsam, weil er/sie müde ist.
88. Der Chef war spät, weil er/sie verschlafen hat.
89. Der Baron ist dick, weil er/sie viel isst.
90. Der Clown ist bunt, weil er/sie verkleidet ist.
91. Der Diener ist anerkannt, weil er/sie fleißig ist.
92. Der Chirurg ist ernst, weil er/sie gerade operiert.
93. Der Laborant ist schüchtern, weil er/sie fremd ist.
94. Der Freund ist neugierig, weil er/sie Gerüchte hörte.
95. Der Häftling ist pfffig, weil er/sie flüchten konnte.
96. Der Held ist stolz, weil er/sie gefeiert wird.
97. Der Gatte ist schläfrig, weil er/sie nachts wacht.
98. Der Mann ist geschickt, weil er/sie viel übt.
99. Der Knecht ist dünn, weil er/sie kaum isst.
100. Der Narr ist verrückt, weil er/sie Unsinn treibt.
101. Der Häuptling ist neidisch, weil er/sie keine Frau bekommt.
102. Der Neffe schleckt Eis, weil er/sie Süßes mag.
103. Der Jäger ist ordentlich, weil er/sie suchen hasst.
104. Der Opa ist zerstreut, weil er/sie alt ist.
105. Der Onkel kauft Süßes, weil er/sie Geschenke braucht.
106. Der Spion ist gespannt, weil er/sie Aufträge hat.

107. Der Schüler ist fleißig, weil er/sie Klausuren schreibt.
108. Der Kapitän kennt Länder, weil er/sie viel segelt.
109. Der Koch ist dickköpfig, weil er/sie egoistisch ist.
110. Der Pfarrer trägt schwarz, weil er/sie Gottesdienst hält.
111. Der Prinz ist eitel, weil er/sie schön ist.
112. Der Kommissar ist effizient, weil er/sie arbeiten muss.
113. Der Monteur ist tatkräftig, weil er/sie bald verreist.
114. Der Zauberer ist witzig, weil er/sie Humor hat.
115. Der General ist interessiert, weil er/sie Projekte hat.
116. Der Hirte ist zuverlässig, weil er/sie Schafe hütet.
117. Der Kamerad ist bescheiden, weil er/sie Freunde hat.
118. Der Journalist ist großzügig, weil er/sie Fotos hat.
119. Der Kaiser ist schlau, weil er/sie Pläne hat.
120. Der Greis ist verschnupft, weil er/sie erkältet ist.

B: Thing as antecedent:

1. Die Tür ist offen, weil sie/er kaputt ist.
2. Die Glocke ist laut, weil sie/er groß ist.
3. Die Vase ist kaputt, weil sie/er gefallen ist.
4. Die Bluse ist schön, weil sie/er gelb ist.
5. Die Aufgabe ist schwer, weil sie/er unlösbar ist.
6. Die Flasche ist ausgelaufen, weil sie/er undicht war.
7. Die Blume ist verblüht, weil sie/er vertrocknet ist.
8. Die Hose ist schmutzig, weil sie/er schlammig ist.
9. Die Tasche ist praktisch, weil sie/er übersichtlich ist.
10. Die Maschine ist laut, weil sie/er wackelig steht.
11. Die Schüssel wird weggeworfen, weil sie/er Risse hat.
12. Die Frisur ist furchtbar, weil sie/er misslungen ist.
13. Die Kneipe ist voll, weil sie/er beliebt ist.
14. Die Jacke ist warm, weil sie/er gefüttert ist.
15. Die Uhr ist genau, weil sie/er gestellt wurde.
16. Die Suppe ist scharf, weil sie/er gewürzt wurde.
17. Die Ampel ist aus, weil sie/er defekt ist.
18. Die Heizung ist heiß, weil sie/er an ist.
19. Die Fabrik ist zerstört, weil sie/er unmodern ist.
20. Die Idee ist genial, weil sie/er einfach ist.
21. Die Socke riecht schlecht, weil sie/er ungewaschen ist.
22. Die Stange ist schwer, weil sie/er bleiern ist.
23. Die Nase trieft stark, weil sie/er verschnupft ist.
24. Die Galerie ist interessant, weil sie/er Werke zeigt.
25. Die Salbe ist lindernd, weil sie/er Schmerzen stillt.
26. Die Limonade ist kalt, weil sie/er gekühlt wurde.
27. Die Truhe ist braun, weil sie/er hölzern ist.
28. Die Wunde ist schmerzend, weil sie/er tief ist.
29. Die Stufe ist schwierig, weil sie/er hoch ist.
30. Die Schere ist scharf, weil sie/er geschliffen wurde.
31. Die Sonne blendet stark, weil sie/er grell ist.
32. Die Schule ist geschlossen, weil sie/er renoviert wird.
33. Die Perle ist wertvoll, weil sie/er selten ist.
34. Die Decke ist unerreichbar, weil sie/er hoch ist.
35. Die Scheibe ist klar, weil sie/er geputzt wurde.
36. Die Butter ist zerlaufen, weil sie/er erwärmt wurde.
37. Die Banane ist matschig, weil sie/er überreif ist.
38. Die Tablette ist ungesund, weil sie/er giftig ist.
39. Die Frucht ist gesund, weil sie/er Vitamine enthält.
40. Die Schiene wird gewechselt, weil sie/er porös ist.
41. Die Gabel hat Gewicht, weil sie/er metallern ist.
42. Die Couch ist bequem, weil sie/er gepolstert ist.
43. Die Tasse ist leer, weil sie/er ausgetrunken wurde.

44. Die Rakete fliegt los, weil sie/er gestartet wurde.
45. Die Kerze brennt hell, weil sie/er angezündet wurde.
46. Die Gitarre ist harmonisch, weil sie/er gestimmt wurde.
47. Die Kette ist teuer, weil sie/er antik ist.
48. Die Halle ist riesig, weil sie/er vergrößert wurde.
49. Die Schachtel ist deformiert, weil sie/er zerdrückt wurde.
50. Die Karte ist gezinkt, weil sie/er markiert wurde.
51. Die Tafel ist beschrieben, weil sie/er genutzt wurde.
52. Die Brille ist durchsichtig, weil sie/er gläsern ist.
53. Die Klinke ist lila, weil sie/er lackiert wurde.
54. Die Straße ist glatt, weil sie/er vereist ist.
55. Die Kirche ist kalt, weil sie/er ungeheizt ist.
56. Die Sohle ist löchrig, weil sie/er durchgelaufen ist.
57. Die Krone funkelt hell, weil sie/er golden ist.
58. Die Binde ist rötlich, weil sie/er blutig ist.
59. Die Tinte ist verschmiert, weil sie/er feucht war.
60. Die Krawatte ist schick, weil sie/er modern ist.

61. Der Tunnel ist dunkel, weil er/sie lang ist.
62. Der Nagel ist rostig, weil er/sie nass war.
63. Der Fernseher ist gut, weil er/sie neu ist.
64. Der Zahn ist hässlich, weil er/sie gelb ist.
65. Der Tee ist schlecht, weil er/sie bitter ist.
66. Der Schuh ist kaputt, weil er/sie alt ist.
67. Der Füller ist pink, weil er/sie auffallen soll.
68. Der Zug ist spät, weil er/sie angehalten wurde.
69. Der Roman ist vergriffen, weil er/sie aufregend ist.
70. Der Mund ist rot, weil er/sie durchblutet ist.
71. Der Kaffee ist stark, weil er/sie aufwecken soll.
72. Der Zettel ist verschwunden, weil er/sie winzig war.
73. Der Garten ist verwildert, weil er/sie unbewohnt ist.
74. Der Topf ist unbrauchbar, weil er/sie löchrig hat.
75. Der Rucksack ist schwer, weil er/sie gepackt ist.
76. Der Anzug ist unbequem, weil er/sie steif ist.
77. Der Braten ist schmackhaft, weil er/sie gar ist.
78. Der Apfel ist süß, weil er/sie reif ist.
79. Der Film ist spannend, weil er/sie neu ist.
80. Der Wein schmeckt gut, weil er/sie trocken ist.
81. Der Herd ist heiß, weil er/sie angestellt ist.
82. Der Zaun ist hoch, weil er/sie schützen soll.
83. Der Gesang ist melodisch, weil er/sie harmonisch ist.
84. Der Saft ist schmackhaft, weil er/sie frisch ist.
85. Der Sessel ist schwer, weil er/sie groß ist.
86. Der Tag ist mild, weil er/sie sonnig ist.
87. Der Wecker ist gestellt, weil er/sie klingeln soll.
88. Der Bach ist geschützt, weil er/sie rein ist.
89. Der Hals ist geschwollen, weil er/sie entzündet ist.
90. Der Pickel ist lästig, weil er/sie schmerzhaft ist.
91. Der Boden ist rutschig, weil er/sie gebohrt wurde.
92. Der Samen keimt schon, weil er/sie gesetzt wurde.
93. Der Wald ist kahl, weil er/sie gerodet wurde.
94. Der Schornstein wird abgerissen, weil er/sie störend ist.
95. Der Reifen ist luftdicht, weil er/sie geflickt wurde.
96. Der Arm ist träge, weil er/sie belastet wurde.
97. Der Wagen kostet viel, weil er/sie neu ist.
98. Der Himmel ist unheimlich, weil er/sie dunkel ist.
99. Der Ballon schwebt oben, weil er/sie leicht ist.
100. Der Whiskey ist angenehm, weil er/sie innen wärmt.
101. Der Rasen ist grün, weil er/sie beregnet wurde.
102. Der Korb ist biegsam, weil er/sie elastisch ist.

103. Der Käse ist flüssig, weil er/sie erwärmt wurde.
104. Der Tank ist voll, weil er/sie gefüllt wurde.
105. Der Scheinwerfer leuchtet wieder, weil er/sie repariert wurde.
106. Der Schirm ist verkäuflich, weil er/sie genäht wurde.
107. Der Mantel ist blau, weil er/sie gefärbt wurde.
108. Der Mond ist unsichtbar, weil er/sie verdeckt ist.
109. Der Ring ist unauffindbar, weil er/sie verschwunden ist.
110. Der Computer ist defekt, weil er/sie vervirt ist.
111. Der Zopf ist kurz, weil er/sie abgeschnitten wurde.
112. Der Berg ist anstrengend, weil er/sie hoch ist.
113. Der Gürtel ist eng, weil er/sie fest ist.
114. Der Balkon ist verboten, weil er/sie brüchig ist.
115. Der Wasserhahn tropft, weil er/sie undicht ist.
116. Der Faden ist zerrissen, weil er/sie überspannt wurde.
117. Der Kiosk ist unbesetzt, weil er/sie geschlossen ist.
118. Der Pudding ist lecker, weil er/sie schokoladig ist.
119. Der Kuchen ist kalorienreich, weil er/sie sahnig ist.
120. Der Teller ist zerbrochen, weil er/sie runter fiel.

Appendix II**Material for Chapter 2 (Experiment 2)**

1.
 - a. Die Blondine hat bald einen Auftritt. Die Bluse ist schön, weil sie seiden ist.
 - b. Die Blondine hat bald einen Auftritt. Die Bluse ist schön, weil sie eitel ist.
 - c. Der Clown hat bald einen Auftritt. Die Bluse ist schön, weil er seiden ist.
 - d. Der Clown hat bald einen Auftritt. Die Bluse ist schön, weil er eitel ist.
 - e. Der Clown hat bald einen Auftritt. Die Bluse ist schön, weil sie seiden ist.
 - f. Der Clown hat bald einen Auftritt. Die Bluse ist schön, weil sie eitel ist.
2.
 - a. Die Zigeunerin ist in einer Backstube. Die Butter ist zerlaufen, weil sie erwärmt wurde.
 - b. Die Zigeunerin ist in einer Backstube. Die Butter ist zerlaufen, weil sie gebacken hat.
 - c. Der Geselle ist in einer Backstube. Die Butter ist zerlaufen, weil er erwärmt wurde.
 - d. Der Geselle ist in einer Backstube. Die Butter ist zerlaufen, weil er gebacken hat.
 - e. Der Geselle ist in einer Backstube. Die Butter ist zerlaufen, weil sie erwärmt wurde.
 - f. Der Geselle ist in einer Backstube. Die Butter ist zerlaufen, weil sie gebacken hat.
3.
 - a. Die Touristin ist auf einer Reise. Die Flasche ist ausgelaufen, weil sie undicht war.
 - b. Die Touristin ist auf einer Reise. Die Flasche ist ausgelaufen, weil sie unvorsichtig war.
 - c. Der Onkel ist auf einer Reise. Die Flasche ist ausgelaufen, weil er undicht war.
 - d. Der Onkel ist auf einer Reise. Die Flasche ist ausgelaufen, weil er unvorsichtig war.
 - e. Der Onkel ist auf einer Reise. Die Flasche ist ausgelaufen, weil sie undicht war.
 - f. Der Onkel ist auf einer Reise. Die Flasche ist ausgelaufen, weil sie unvorsichtig war.
4.
 - a. Die Ballerina ist in einem Salon. Die Frisur ist furchtbar, weil sie misslungen ist.
 - b. Die Ballerina ist in einem Salon. Die Frisur ist furchtbar, weil sie gewackelt hat.
 - c. Der Anwalt ist in einem Salon. Die Frisur ist furchtbar, weil er misslungen ist.
 - d. Der Anwalt ist in einem Salon. Die Frisur ist furchtbar, weil er gewackelt hat.
 - e. Der Anwalt ist in einem Salon. Die Frisur ist furchtbar, weil sie misslungen ist.
 - f. Der Anwalt ist in einem Salon. Die Frisur ist furchtbar, weil sie gewackelt hat.
5.
 - a. Die Gitarristin ist in einem Konzert. Die Gitarre ist harmonisch, weil sie gestimmt wurde.
 - b. Die Gitarristin ist in einem Konzert. Die Gitarre ist harmonisch, weil sie musikalisch ist.
 - c. Der Gitarrist ist in einem Konzert. Die Gitarre ist harmonisch, weil er gestimmt wurde.
 - d. Der Gitarrist ist in einem Konzert. Die Gitarre ist harmonisch, weil er musikalisch ist.
 - e. Der Gitarrist ist in einem Konzert. Die Gitarre ist harmonisch, weil sie gestimmt wurde.
 - f. Der Gitarrist ist in einem Konzert. Die Gitarre ist harmonisch, weil sie musikalisch ist.
6.
 - a. Die Nonne ist in einem Kirchturm. Die Glocke ist laut, weil sie metallern ist.
 - b. Die Nonne ist in einem Kirchturm. Die Glocke ist laut, weil sie kräftig zieht.
 - c. Der Pfarrer ist in einem Kirchturm. Die Glocke ist laut, weil er metallern ist.
 - d. Der Pfarrer ist in einem Kirchturm. Die Glocke ist laut, weil er kräftig zieht.
 - e. Der Pfarrer ist in einem Kirchturm. Die Glocke ist laut, weil sie metallern ist.
 - f. Der Pfarrer ist in einem Kirchturm. Die Glocke ist laut, weil sie kräftig zieht.
7.
 - a. Die Schwester spielt im Wald. Die Hose ist schmutzig, weil sie schlammig ist.
 - b. Die Schwester spielt im Wald. Die Hose ist schmutzig, weil sie gestürzt ist.
 - c. Der Bruder spielt im Wald. Die Hose ist schmutzig, weil er schlammig ist.
 - d. Der Bruder spielt im Wald. Die Hose ist schmutzig, weil er gestürzt ist.
 - e. Der Bruder spielt im Wald. Die Hose ist schmutzig, weil sie schlammig ist.
 - f. Der Bruder spielt im Wald. Die Hose ist schmutzig, weil sie gestürzt ist.

- 8.
- a. Die Frau steht im kalten Schnee. Die Jacke ist warm, weil sie gefüttert ist.
 - b. Die Frau steht im kalten Schnee. Die Jacke ist warm, weil sie friert schnell.
 - c. Der Mann steht im kalten Schnee. Die Jacke ist warm, weil er gefüttert ist.
 - d. Der Mann steht im kalten Schnee. Die Jacke ist warm, weil er friert schnell.
 - e. Der Mann steht im kalten Schnee. Die Jacke ist warm, weil sie gefüttert ist.
 - f. Der Mann steht im kalten Schnee. Die Jacke ist warm, weil sie friert schnell.
- 9.
- a. Die Tochter spielt in einem Salon. Die Karte ist gezinkt, weil sie markiert ist.
 - b. Die Tochter spielt in einem Salon. Die Karte ist gezinkt, weil sie häufig schummelt.
 - c. Der Sohn spielt in einem Salon. Die Karte ist gezinkt, weil er markiert ist.
 - d. Der Sohn spielt in einem Salon. Die Karte ist gezinkt, weil er häufig schummelt.
 - e. Der Sohn spielt in einem Salon. Die Karte ist gezinkt, weil sie markiert ist.
 - f. Der Sohn spielt in einem Salon. Die Karte ist gezinkt, weil sie häufig schummelt.
- 10.
- a. Die Hexe sitzt im dunklen Keller. Die Kerze brennt hell, weil sie angezündet wurde.
 - b. Die Hexe sitzt im dunklen Keller. Die Kerze brennt hell, weil sie sehen möchte.
 - c. Der Zauberer sitzt im dunklen Keller. Die Kerze brennt hell, weil er angezündet wurde.
 - d. Der Zauberer sitzt im dunklen Keller. Die Kerze brennt hell, weil er sehen möchte.
 - e. Der Zauberer sitzt im dunklen Keller. Die Kerze brennt hell, weil sie angezündet wurde.
 - f. Der Zauberer sitzt im dunklen Keller. Die Kerze brennt hell, weil sie sehen möchte.
- 11.
- a. Die Diva steht in einem Schmuckladen. Die Kette ist teuer, weil sie antik ist.
 - b. Die Diva steht in einem Schmuckladen. Die Kette ist teuer, weil sie reich ist.
 - c. Der Direktor steht in einem Schmuckladen. Die Kette ist teuer, weil er antik ist.
 - d. Der Direktor steht in einem Schmuckladen. Die Kette ist teuer, weil er reich ist.
 - e. Der Direktor steht in einem Schmuckladen. Die Kette ist teuer, weil sie antik ist.
 - f. Der Direktor steht in einem Schmuckladen. Die Kette ist teuer, weil sie reich ist.
- 12.
- a. Die Magd ist in einer Fabrik. Die Maschine ist laut, weil sie kaputt ist.
 - b. Die Magd ist in einer Fabrik. Die Maschine ist laut, weil sie ahnungslos ist.
 - c. Der Pate ist in einer Fabrik. Die Maschine ist laut, weil er kaputt ist.
 - d. Der Pate ist in einer Fabrik. Die Maschine ist laut, weil er ahnungslos ist.
 - e. Der Pate ist in einer Fabrik. Die Maschine ist laut, weil sie kaputt ist.
 - f. Der Pate ist in einer Fabrik. Die Maschine ist laut, weil sie ahnungslos ist.
- 13.
- a. Die Pflegerin ist in einem Krankenhaus. Die Nase trieft, weil sie verstopft ist.
 - b. Die Pflegerin ist in einem Krankenhaus. Die Nase trieft, weil sie erkältet ist.
 - c. Der Patient ist in einem Krankenhaus. Die Nase trieft, weil er verstopft ist.
 - d. Der Patient ist in einem Krankenhaus. Die Nase trieft, weil er erkältet ist.
 - e. Der Patient ist in einem Krankenhaus. Die Nase trieft, weil sie verstopft ist.
 - f. Der Patient ist in einem Krankenhaus. Die Nase trieft, weil sie erkältet ist.
- 14.
- a. Die Braut ist in einem Laden. Die Schachtel ist deformiert, weil sie zerdrückt wurde.
 - b. Die Braut ist in einem Laden. Die Schachtel ist deformiert, weil sie draufgetreten ist.
 - c. Der Gatte ist in einem Laden. Die Schachtel ist deformiert, weil er zerdrückt wurde.
 - d. Der Gatte ist in einem Laden. Die Schachtel ist deformiert, weil er draufgetreten ist.
 - e. Der Gatte ist in einem Laden. Die Schachtel ist deformiert, weil sie zerdrückt wurde.
 - f. Der Gatte ist in einem Laden. Die Schachtel ist deformiert, weil sie draufgetreten ist.

15.

- a. Die Kundin ist in einem Schuhladen. Die Socke riecht schlecht, weil sie ungewaschen ist.
- b. Die Kundin ist in einem Schuhladen. Die Socke riecht schlecht, weil sie schwitzt sehr.
- c. Der Punker ist in einem Schuhladen. Die Socke riecht schlecht, weil er ungewaschen ist.
- d. Der Punker ist in einem Schuhladen. Die Socke riecht schlecht, weil er schwitzt sehr.
- e. Der Punker ist in einem Schuhladen. Die Socke riecht schlecht, weil sie ungewaschen ist.
- f. Der Punker ist in einem Schuhladen. Die Socke riecht schlecht, weil sie schwitzt sehr.

16.

- a. Die Nichte hat einen Schuh an. Die Sohle ist löchrig, weil sie durchgelaufen ist.
- b. Die Nichte hat einen Schuh an. Die Sohle ist löchrig, weil sie arm ist.
- c. Der Neffe hat einen Schuh an. Die Sohle ist löchrig, weil er durchgelaufen ist.
- d. Der Neffe hat einen Schuh an. Die Sohle ist löchrig, weil er arm ist.
- e. Der Neffe hat einen Schuh an. Die Sohle ist löchrig, weil sie durchgelaufen ist.
- f. Der Neffe hat einen Schuh an. Die Sohle ist löchrig, weil sie arm ist.

17.

- a. Die Fürstin ist in einem Atelier. Die Skulptur ist anmutig, weil sie filigran ist.
- b. Die Fürstin ist in einem Atelier. Die Skulptur ist anmutig, weil sie talentiert ist.
- c. Der Künstler ist in einem Atelier. Die Skulptur ist anmutig, weil er filigran ist.
- d. Der Künstler ist in einem Atelier. Die Skulptur ist anmutig, weil er talentiert ist.
- e. Der Künstler ist in einem Atelier. Die Skulptur ist anmutig, weil sie filigran ist.
- f. Der Künstler ist in einem Atelier. Die Skulptur ist anmutig, weil sie talentiert ist.

18.

- a. Die Rentnerin läuft selten im Winter. Die Strasse ist glatt, weil sie eisig ist.
- b. Die Rentnerin läuft selten im Winter. Die Strasse ist glatt, weil sie gerutscht ist.
- c. Der Rentner läuft selten im Winter. Die Strasse ist glatt, weil er eisig ist.
- d. Der Rentner läuft selten im Winter. Die Strasse ist glatt, weil er gerutscht ist.
- e. Der Rentner läuft selten im Winter. Die Strasse ist glatt, weil sie eisig ist.
- f. Der Rentner läuft selten im Winter. Die Strasse ist glatt, weil sie gerutscht ist.

19.

- a. Die Witwe isst in einem Restaurant. Die Suppe ist scharf, weil sie gewürzt ist.
- b. Die Witwe isst in einem Restaurant. Die Suppe ist scharf, weil sie bevorzugt Würze.
- c. Der Minister isst in einem Restaurant. Die Suppe ist scharf, weil er gewürzt ist.
- d. Der Minister isst in einem Restaurant. Die Suppe ist scharf, weil er bevorzugt Würze.
- e. Der Minister isst in einem Restaurant. Die Suppe ist scharf, weil sie gewürzt ist.
- f. Der Minister isst in einem Restaurant. Die Suppe ist scharf, weil sie bevorzugt Würze.

20.

- a. Die Lehrerin ist in einer Schule. Die Tafel ist beschrieben, weil sie genutzt wurde.
- b. Die Lehrerin ist in einer Schule. Die Tafel ist beschrieben, weil sie erklärt hat.
- c. Der Lehrer ist in einer Schule. Die Tafel ist beschrieben, weil er genutzt wurde.
- d. Der Lehrer ist in einer Schule. Die Tafel ist beschrieben, weil er erklärt hat.
- e. Der Lehrer ist in einer Schule. Die Tafel ist beschrieben, weil sie genutzt wurde.
- f. Der Lehrer ist in einer Schule. Die Tafel ist beschrieben, weil sie erklärt hat.

21.

- a. Die Kellnerin ist in einer Küche. Die Tasse ist leer, weil sie abgewaschen ist.
- b. Die Kellnerin ist in einer Küche. Die Tasse ist leer, weil sie getrunken hat.
- c. Der Vater ist in einer Küche. Die Tasse ist leer, weil er abgewaschen ist.
- d. Der Vater ist in einer Küche. Die Tasse ist leer, weil er getrunken hat.
- e. Der Vater ist in einer Küche. Die Tasse ist leer, weil sie abgewaschen ist.
- f. Der Vater ist in einer Küche. Die Tasse ist leer, weil sie getrunken hat.

22.

- a. Die Tante ist in einer Tischlerei. Die Truhe ist braun, weil sie hölzern ist.
- b. Die Tante ist in einer Tischlerei. Die Truhe ist braun, weil sie Geschmack hat.
- c. Der Kommissar ist in einer Tischlerei. Die Truhe ist braun, weil sie hölzern ist.
- d. Der Kommissar ist in einer Tischlerei. Die Truhe ist braun, weil er Geschmack hat.
- e. Der Kommissar ist in einer Tischlerei. Die Truhe ist braun, weil sie hölzern ist.
- f. Der Kommissar ist in einer Tischlerei. Die Truhe ist braun, weil sie Geschmack hat.

23.

- a. Die Sekretärin ist in einer Wohnung. Die Tür ist offen, weil sie kaputt ist.
- b. Die Sekretärin ist in einer Wohnung. Die Tür ist offen, weil sie verreisen möchte.
- c. Der General ist in einer Wohnung. Die Tür ist offen, weil er kaputt ist.
- d. Der General ist in einer Wohnung. Die Tür ist offen, weil er verreisen möchte.
- e. Der General ist in einer Wohnung. Die Tür ist offen, weil sie kaputt ist.
- f. Der General ist in einer Wohnung. Die Tür ist offen, weil sie verreisen möchte.

24.

- a. Die Königin ist in großer Eile. Die Uhr ist genau, weil sie gestellt wurde.
- b. Die Königin ist in großer Eile. Die Uhr ist genau, weil sie pünktlich ist.
- c. Der Journalist ist in großer Eile. Die Uhr ist genau, weil er gestellt wurde.
- d. Der Journalist ist in großer Eile. Die Uhr ist genau, weil er pünktlich ist.
- e. Der Journalist ist in großer Eile. Die Uhr ist genau, weil sie gestellt wurde.
- f. Der Journalist ist in großer Eile. Die Uhr ist genau, weil sie pünktlich ist.

25.

- a. Die Sklavin ist in einem Blumengeschäft. Die Vase ist kaputt, weil sie zersprungen ist.
- b. Die Sklavin ist in einem Blumengeschäft. Die Vase ist kaputt, weil sie tollpatschig ist.
- c. Der Schüler ist in einem Blumengeschäft. Die Vase ist kaputt, weil er zersprungen ist.
- d. Der Schüler ist in einem Blumengeschäft. Die Vase ist kaputt, weil sie tollpatschig ist.
- e. Der Schüler ist in einem Blumengeschäft. Die Vase ist kaputt, weil er zersprungen ist.
- f. Der Schüler ist in einem Blumengeschäft. Die Vase ist kaputt, weil sie tollpatschig ist.

26.

- a. Der Abiturient ist in einer Garderobe. Der Anzug ist unbequem, weil er kratzig ist.
- b. Der Abiturient ist in einer Garderobe. Der Anzug ist unbequem, weil er nervös ist.
- c. Die Dozentin ist in einer Garderobe. Der Anzug ist unbequem, weil sie kratzig ist.
- d. Die Dozentin ist in einer Garderobe. Der Anzug ist unbequem, weil sie nervös ist.
- e. Die Dozentin ist in einer Garderobe. Der Anzug ist unbequem, weil er kratzig ist.
- f. Die Dozentin ist in einer Garderobe. Der Anzug ist unbequem, weil er nervös ist.

27.

- a. Der Jongleur ist in einem Wettkampf. Der Arm ist träge, weil er schmerzhaft ist.
- b. Der Jongleur ist in einem Wettkampf. Der Arm ist träge, weil er unbesonnen trainiert.
- c. Die Sportlerin ist in einem Wettkampf. Der Arm ist träge, weil sie schmerzhaft ist.
- d. Die Sportlerin ist in einem Wettkampf. Der Arm ist träge, weil sie unbesonnen trainiert.
- e. Die Sportlerin ist in einem Wettkampf. Der Arm ist träge, weil er schmerzhaft ist.
- f. Die Sportlerin ist in einem Wettkampf. Der Arm ist träge, weil er unbesonnen trainiert.

28.

- a. Der Fischer ist in einem Verein. Der Bach wird geschützt, weil er rein ist.
- b. Der Fischer ist in einem Verein. Der Bach wird geschützt, weil er umweltbewusst ist.
- c. Die Verkäuferin ist in einem Verein. Der Bach wird geschützt, weil sie rein ist.
- d. Die Verkäuferin ist in einem Verein. Der Bach wird geschützt, weil sie umweltbewusst ist.
- e. Die Verkäuferin ist in einem Verein. Der Bach wird geschützt, weil er rein ist.
- f. Die Verkäuferin ist in einem Verein. Der Bach wird geschützt, weil er umweltbewusst ist.

29.

- a. Der Bauleiter ist auf einer Baustelle. Der Balkon ist verboten, weil er brüchig ist.
- b. Der Bauleiter ist auf einer Baustelle. Der Balkon ist verboten, weil er verantwortlich ist.
- c. Die Architektin ist auf einer Baustelle. Der Balkon ist verboten, weil sie brüchig ist.
- d. Die Architektin ist auf einer Baustelle. Der Balkon ist verboten, weil sie verantwortlich ist.
- e. Die Architektin ist auf einer Baustelle. Der Balkon ist verboten, weil er brüchig ist.
- f. Die Architektin ist auf einer Baustelle. Der Balkon ist verboten, weil er verantwortlich ist.

30.

- a. Der Metzger ist in einer Fleischerei. Der Braten ist schmackhaft, weil er gar ist.
- b. Der Metzger ist in einer Fleischerei. Der Braten ist schmackhaft, weil er talentiert kocht.
- c. Die Jungfer ist in einer Fleischerei. Der Braten ist schmackhaft, weil sie gar ist.
- d. Die Jungfer ist in einer Fleischerei. Der Braten ist schmackhaft, weil sie talentiert kocht.
- e. Die Jungfer ist in einer Fleischerei. Der Braten ist schmackhaft, weil er gar ist.
- f. Die Jungfer ist in einer Fleischerei. Der Braten ist schmackhaft, weil er talentiert kocht.

31.

- a. Der Knecht näht eine Bluse. Der Faden ist zerrissen, weil er porös war.
- b. Der Knecht näht eine Bluse. Der Faden ist zerrissen, weil er wütend zog.
- c. Die Dame näht eine Bluse. Der Faden ist zerrissen, weil sie porös war.
- d. Die Dame näht eine Bluse. Der Faden ist zerrissen, weil sie wütend zog.
- e. Die Dame näht eine Bluse. Der Faden ist zerrissen, weil er porös.
- f. Die Dame näht eine Bluse. Der Faden ist zerrissen, weil er kräftig zog.

32.

- a. Der Opa ist in einem Heim. Der Garten ist verwildert, weil er ungepflegt ist.
- b. Der Opa ist in einem Heim. Der Garten ist verwildert, weil er krank ist.
- c. Die Oma ist in einem Heim. Der Garten ist verwildert, weil sie ungepflegt ist.
- d. Die Oma ist in einem Heim. Der Garten ist verwildert, weil sie krank ist.
- e. Die Oma ist in einem Heim. Der Garten ist verwildert, weil er ungepflegt ist.
- f. Die Oma ist in einem Heim. Der Garten ist verwildert, weil er krank ist.

33.

- a. Der Sänger bleibt heute im Bett. Der Hals ist geschwollen, weil er entzündet ist.
- b. Der Sänger bleibt heute im Bett. Der Hals ist geschwollen, weil er krank ist.
- c. Die Athletin bleibt heute im Bett. Der Hals ist geschwollen, weil sie entzündet ist.
- d. Die Athletin bleibt heute im Bett. Der Hals ist geschwollen, weil sie krank ist.
- e. Die Athletin bleibt heute im Bett. Der Hals ist geschwollen, weil er entzündet ist.
- f. Die Athletin bleibt heute im Bett. Der Hals ist geschwollen, weil er krank ist.

34.

- a. Der Jäger ist schon sehr hungrig. Der Herd ist heiß, weil er angeschaltet ist.
- b. Der Jäger ist schon sehr hungrig. Der Herd ist heiß, weil er kochen möchte.
- c. Die Polin ist schon sehr hungrig. Der Herd ist heiß, weil sie angeschaltet ist.
- d. Die Polin ist schon sehr hungrig. Der Herd ist heiß, weil er kochen möchte.
- e. Die Polin ist schon sehr hungrig. Der Herd ist heiß, weil sie angeschaltet ist.
- f. Die Polin ist schon sehr hungrig. Der Herd ist heiß, weil er kochen möchte.

35.

- a. Der Professor steht sehr früh auf. Der Kaffee ist stark, weil er aufwecken soll.
- b. Der Professor steht sehr früh auf. Der Kaffee ist stark, weil er aufwachen muss.
- c. Die Lehrerin steht sehr früh auf. Der Kaffee ist stark, weil sie aufwecken soll.
- d. Die Lehrerin steht sehr früh auf. Der Kaffee ist stark, weil sie aufwachen muss.
- e. Die Lehrerin steht sehr früh auf. Der Kaffee ist stark, weil er aufwecken soll.
- f. Die Lehrerin steht sehr früh auf. Der Kaffee ist stark, weil er aufwachen muss.

36.

- a. Der Moderator ist auf der Kellertreppe. Der Keller ist unheimlich, weil er dunkel ist.
- b. Der Moderator ist auf der Kellertreppe. Der Keller ist unheimlich, weil er ängstlich ist.
- c. Die Reporterin ist auf der Kellertreppe. Der Keller ist unheimlich, weil sie dunkel ist.
- d. Die Reporterin ist auf der Kellertreppe. Der Keller ist unheimlich, weil sie ängstlich ist.
- e. Die Reporterin ist auf der Kellertreppe. Der Keller ist unheimlich, weil er dunkel ist.
- f. Die Reporterin ist auf der Kellertreppe. Der Keller ist unheimlich, weil er ängstlich ist.

37.

- a. Der Neffe ist in einem Café. Der Kuchen ist kalorienreich, weil er sahnig ist.
- b. Der Neffe ist in einem Café. Der Kuchen ist kalorienreich, weil er zunehmen muss.
- c. Die Nichte ist in einem Café. Der Kuchen ist kalorienreich, weil sie sahnig ist.
- d. Die Nichte ist in einem Café. Der Kuchen ist kalorienreich, weil sie zunehmen muss.
- e. Die Nichte ist in einem Café. Der Kuchen ist kalorienreich, weil er sahnig ist.
- f. Die Nichte ist in einem Café. Der Kuchen ist kalorienreich, weil er zunehmen muss.

38.

- a. Der Narr hat bald einen Auftritt. Der Mund ist rot, weil er durchblutet ist.
- b. Der Narr hat bald einen Auftritt. Der Mund ist rot, weil er erkältet ist.
- c. Die Kandidatin hat bald einen Auftritt. Der Mund ist rot, weil sie durchblutet ist.
- d. Die Kandidatin hat bald einen Auftritt. Der Mund ist rot, weil sie erkältet ist.
- e. Die Kandidatin hat bald einen Auftritt. Der Mund ist rot, weil er durchblutet ist.
- f. Die Kandidatin hat bald einen Auftritt. Der Mund ist rot, weil er erkältet ist.

39.

- a. Der Koch ist in einem Restaurant. Der Pudding ist lecker, weil er schokoladig ist.
- b. Der Koch ist in einem Restaurant. Der Pudding ist lecker, weil er liebevoll kocht.
- c. Die Köchin ist in einem Restaurant. Der Pudding ist lecker, weil sie schokoladig ist.
- d. Die Köchin ist in einem Restaurant. Der Pudding ist lecker, weil sie liebevoll kocht.
- e. Die Köchin ist in einem Restaurant. Der Pudding ist lecker, weil er schokoladig ist.
- f. Die Köchin ist in einem Restaurant. Der Pudding ist lecker, weil er liebevoll kocht.

40.

- a. Der Hirte ist in einem Garten. Der Rasen ist grün, weil er beregnet wurde.
- b. Der Hirte ist in einem Garten. Der Rasen ist grün, weil er fanatisch düngt.
- c. Die Forscherin ist in einem Garten. Der Rasen ist grün, weil sie beregnet wurde.
- d. Die Forscherin ist in einem Garten. Der Rasen ist grün, weil sie fanatisch düngt.
- e. Die Forscherin ist in einem Garten. Der Rasen ist grün, weil er beregnet wurde.
- f. Die Forscherin ist in einem Garten. Der Rasen ist grün, weil er fanatisch düngt.

41.

- a. Der Gärtner ist in einem Beet. Der Samen keimt schon, weil er gesetzt wurde.
- b. Der Gärtner ist in einem Beet. Der Samen keimt schon, weil er sorgsam wässert.
- c. Die Sklavin ist in einem Beet. Der Samen keimt schon, weil sie gesetzt wurde.
- d. Die Sklavin ist in einem Beet. Der Samen keimt schon, weil sie sorgsam wässert.
- e. Die Sklavin ist in einem Beet. Der Samen keimt schon, weil er gesetzt wurde.
- f. Die Sklavin ist in einem Beet. Der Samen keimt schon, weil er sorgsam wässert.

42.

- a. Der Sänger hat heute einen Umzug. Der Sessel ist schwer, weil er groß ist.
- b. Der Sänger hat heute einen Umzug. Der Sessel ist schwer, weil er schwach ist.
- c. Die Ärztin hat heute einen Umzug. Der Sessel ist schwer, weil sie groß ist.
- d. Die Ärztin hat heute einen Umzug. Der Sessel ist schwer, weil sie schwach ist.
- e. Die Ärztin hat heute einen Umzug. Der Sessel ist schwer, weil er groß ist.
- f. Die Ärztin hat heute einen Umzug. Der Sessel ist schwer, weil er schwach ist.

43.

- a. Der Ingenieur ist an einer Tankstelle. Der Tank ist voll, weil er gefüllt wurde.
- b. Der Ingenieur ist an einer Tankstelle. Der Tank ist voll, weil er getankt hat.
- c. Die Kundin ist an einer Tankstelle. Der Tank ist voll, weil sie gefüllt wurde.
- d. Die Kundin ist an einer Tankstelle. Der Tank ist voll, weil sie getankt hat.
- e. Die Kundin ist an einer Tankstelle. Der Tank ist voll, weil er gefüllt wurde.
- f. Die Kundin ist an einer Tankstelle. Der Tank ist voll, weil er getankt hat.

44.

- a. Der Richter ist in einem Schutzprogramm. Der Zaun ist hoch, weil er elektrisch ist.
- b. Der Richter ist in einem Schutzprogramm. Der Zaun ist hoch, weil er bedroht wird.
- c. Die Zeugin ist in einem Schutzprogramm. Der Zaun ist hoch, weil sie elektrisch ist.
- d. Die Zeugin ist in einem Schutzprogramm. Der Zaun ist hoch, weil sie bedroht wird.
- e. Die Zeugin ist in einem Schutzprogramm. Der Zaun ist hoch, weil er elektrisch ist.
- f. Die Zeugin ist in einem Schutzprogramm. Der Zaun ist hoch, weil er bedroht wird.

45.

- a. Der Geselle sucht in einer Werkstatt. Der Zettel ist verschwunden, weil er winzig ist.
- b. Der Geselle sucht in einer Werkstatt. Der Zettel ist verschwunden, weil er unordentlich ist.
- c. Die Schneiderin sucht in einer Werkstatt. Der Zettel ist verschwunden, weil er winzig ist.
- d. Die Schneiderin sucht in einer Werkstatt. Der Zettel ist verschwunden, weil er unordentlich ist.
- e. Die Schneiderin sucht in einer Werkstatt. Der Zettel ist verschwunden, weil er winzig ist.
- f. Die Schneiderin sucht in einer Werkstatt. Der Zettel ist verschwunden, weil er unordentlich ist.

46.

- a. Der Siedler ist in einer Küche. Der Reis ist weich, weil er verkocht wurde.
- b. Der Siedler ist in einer Küche. Der Reis ist weich, weil er abgelenkt wurde.
- c. Die Chinesin ist in einer Küche. Der Reis ist weich, weil sie verkocht wurde.
- d. Die Chinesin ist in einer Küche. Der Reis ist weich, weil sie abgelenkt wurde.
- e. Die Chinesin ist in einer Küche. Der Reis ist weich, weil er verkocht wurde.
- f. Die Chinesin ist in einer Küche. Der Reis ist weich, weil er abgelenkt wurde.

47.

- a. Der Graf sitzt in einem Café. Der Tee ist schlecht, weil er bitter ist.
- b. Der Graf sitzt in einem Café. Der Tee ist schlecht, weil er pingelig ist.
- c. Die Baronin sitzt in einem Café. Der Tee ist schlecht, weil sie bitter ist.
- d. Die Baronin sitzt in einem Café. Der Tee ist schlecht, weil sie pingelig ist.
- e. Die Baronin sitzt in einem Café. Der Tee ist schlecht, weil er bitter ist.
- f. Die Baronin sitzt in einem Café. Der Tee ist schlecht, weil er pingelig ist.

48.

- a. Der Chef ist in einem Hotel. Der Teller ist zerbrochen, weil er zerscheppt ist.
- b. Der Chef ist in einem Hotel. Der Teller ist zerbrochen, weil er gestolpert ist.
- c. Die Ballerina ist in einem Hotel. Der Teller ist zerbrochen, weil sie zerscheppt ist.
- d. Die Ballerina ist in einem Hotel. Der Teller ist zerbrochen, weil sie gestolpert ist.
- e. Die Ballerina ist in einem Hotel. Der Teller ist zerbrochen, weil er zerscheppt ist.
- f. Die Ballerina ist in einem Hotel. Der Teller ist zerbrochen, weil er gestolpert ist.

49.

- a. Der Schlosser geht in ein Bett. Der Wecker ist gestellt, weil er klingeln soll.
- b. Der Schlosser geht in ein Bett. Der Wecker ist gestellt, weil er aufstehen muss.
- c. Die Stewardess geht in ein Bett. Der Wecker ist gestellt, weil sie klingeln soll.
- d. Die Stewardess geht in ein Bett. Der Wecker ist gestellt, weil sie aufstehen muss.
- e. Die Stewardess geht in ein Bett. Der Wecker ist gestellt, weil er klingeln soll.
- f. Die Stewardess geht in ein Bett. Der Wecker ist gestellt, weil er aufstehen muss.

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- a. Der Bettler ist in einer Praxis. Der Zahn ist hässlich, weil er gelb ist.
- b. Der Bettler ist in einer Praxis. Der Zahn ist hässlich, weil er putzen vermeidet.
- c. Die Forscherin ist in einer Praxis. Der Zahn ist hässlich, weil sie gelb ist.
- d. Die Forscherin ist in einer Praxis. Der Zahn ist hässlich, weil sie putzen vermeidet.
- e. Die Forscherin ist in einer Praxis. Der Zahn ist hässlich, weil er gelb ist.
- f. Die Forscherin ist in einer Praxis. Der Zahn ist hässlich, weil er putzen vermeidet.

Appendix III

Material for Chapter 5 and 6.

Person as antecedent

1	SD	Die Arbeiterin ist eingestellt, weil sie/er zuverlässig ist.
	LD	Die Arbeiterin wird wieder eingestellt und kann verdienen, weil sie/er zuverlässig ist.
2	SD	Die Athletin ist muskulös, weil sie/er Sport treibt.
	LD	Die Athletin ist richtig fit und ist muskulös, weil sie/er Sport treibt.
3	SD	Die Ballerina schreibt Autogramme, weil sie/er berühmt ist.
	LD	Die Ballerina ist sehr gefragt und schreibt Autogramme, weil sie/er berühmt ist.
4	SD	Die Baronin ist glücklich, weil sie/er bald heiratet.
	LD	Die Baronin ist sehr nervös und ist glücklich, weil sie/er bald heiratet.
5	SD	Die Beamtin ist gestresst, weil sie/er Kinder hat.
	LD	Die Beamtin kann selten entspannen und ist gestresst, weil sie/er Kinder hat.
6	SD	Die Blondine wollte schwimmen, weil sie/er Wasser mag.
	LD	Die Blondine ist gern draußen und wollte schwimmen, weil sie/er Wasser mag.
7	SD	Die Braut ist zittrig, weil sie/er aufgeregt ist.
	LD	Die Braut ist heute blass und ist zittrig, weil sie/er aufgeregt ist.
8	SD	Die Chefin ist verzweifelt, weil sie/er betrogen wurde.
	LD	Die Chefin ist total ruiniert und ist verzweifelt, weil sie/er betrogen wurde.
9	SD	Die Dame ist traurig, weil sie/er einsam ist.
	LD	Die Dame ist oft deprimiert und ist traurig, weil sie/er einsam ist.
10	SD	Die Diva ist stur, weil sie/er hochnäsig ist.
	LD	Die Diva sagt nie danke und ist stur, weil sie/er hochnäsig ist.
11	SD	Die Dozentin ist streng, weil sie/er viel fordert.
	LD	Die Dozentin kann selten verzeihen und ist streng, weil sie/er viel fordert.
12	SD	Die Enkelin ist niedlich, weil sie/er klein ist.
	LD	Die Enkelin hat rote Haare und ist niedlich, weil sie/er klein ist.
13	SD	Die Erzieherin ist müde, weil sie/er viel arbeitet.
	LD	Die Erzieherin geht heute einkaufen und ist müde, weil sie/er viel arbeitet.
14	SD	Die Forscherin ist wissbegierig, weil sie/er interessiert ist.
	LD	Die Forscherin liest häufig abends und ist wissbegierig, weil sie/er interessiert ist.
15	SD	Die Frau ist beliebt, weil sie/er schön ist.
	LD	Die Frau wird oft fotografiert und ist beliebt, weil sie/er schön ist.
16	SD	Die Freundin backt Kuchen, weil sie/er Geburtstag hat.
	LD	Die Freundin gibt eine Feier und backt Kuchen, weil sie/er Geburtstag hat.
17	SD	Die Gattin ist geizig, weil sie/er arm ist.
	LD	Die Gattin muss sparsam sein und ist geizig, weil sie/er arm ist.
18	SD	Die Göttin wird verehrt, weil sie/er großzügig ist.
	LD	Die Göttin ist sehr gut und wird verehrt, weil sie/er großzügig ist.
19	SD	Die Gouvernante kauft Kleider, weil sie/er eitel ist.
	LD	Die Gouvernante verschwendet viel Geld und kauft Kleider, weil sie/er eitel ist.
20	SD	Die Greisin ist weise, weil sie/er alt ist.
	LD	Die Greisin wird noch anerkannt und ist weise, weil sie/er alt ist.
21	SD	Die Heldin erlebt Abenteuer, weil sie/er mutig ist.
	LD	Die Heldin geht auf Reisen und erlebt Abenteuer, weil sie/er mutig ist.
22	SD	Die Hexe ist aufgeregt, weil sie/er Besuch hat.
	LD	Die Hexe beginnt mit kochen und ist aufgeregt, weil sie/er Besuch hat.
23	SD	Die Irin ist spontan, weil sie/er verreisen möchte.
	LD	Die Irin packt schon alles und ist spontan, weil sie/er verreisen möchte.
24	SD	Die Jungfer wird ignoriert, weil sie/er klein ist.
	LD	Die Jungfer ist oft traurig und wird ignoriert, weil sie/er klein ist.
25	SD	Die Kaiserin ist ideenreich, weil sie/er kreativ ist.
	LD	Die Kaiserin hat alles verändert und ist ideenreich, weil sie/er kreativ ist.
26	SD	Die Kameradin war böse, weil sie/er zuhause blieb.
	LD	Die Kameradin wurde heute enttäuscht und war böse, weil sie/er zuhause blieb.
27	SD	Die Kandidatin ist schwanger, weil sie/er Kinder mag.
	LD	Die Kandidatin kauft ein Bett und ist schwanger, weil sie/er Kinder mag.

- 28 SD Die Kauffrau ist verschuldet, weil sie/er unaufmerksam war.
LD Die Kauffrau muss nun aufgeben und ist verschuldet, weil sie/er unaufmerksam war.
- 29 SD Die Kellnerin ist unsicher, weil sie/er heute beginnt.
LD Die Kellnerin verschüttet die Getränke und ist unsicher, weil sie/er heute beginnt.
- 30 SD Die Köchin ist verschwitzt, weil sie/er viel arbeitet.
LD Die Köchin mag nach Hause und ist verschwitzt, weil sie/er viel arbeitet.
- 31 SD Die Königin ist beliebt, weil sie/er gut ist.
LD Die Königin wird sehr verehrt und ist beliebt, weil sie/er gut ist.
- 32 SD Die Konkurrentin ist schroff, weil sie/er benachteiligt wurde.
LD Die Konkurrentin kann ungemütlich sein und ist schroff, weil sie/er benachteiligt wurde.
- 33 SD Die Kundin ist modisch, weil sie/er gefallen möchte.
LD Die Kundin kauft neue Sachen und ist modisch, weil sie/er gefallen möchte.
- 34 SD Die Lehrerin unterrichtet gut, weil sie/er spontan ist.
LD Die Lehrerin mag die Arbeit und unterrichtet gut, weil sie/er spontan ist.
- 35 SD Die Magd hat frei, weil sie/er Urlaub hat.
LD Die Magd packt schon zusammen und hat frei, weil sie/er Urlaub hat.
- 36 SD Die Nichte ist allein, weil sie/er oft umzog.
LD Die Nichte geht selten aus und ist allein, weil sie/er oft umzog.
- 37 SD Die Nonne ist fromm, weil sie/er gläubig ist.
LD Die Nonne ist sehr bescheiden und ist fromm, weil sie/er gläubig ist.
- 38 SD Die Oma liest gern, weil sie/er Geschichten mag.
LD Die Oma hat viele Bücher und liest gern, weil sie/er Geschichten mag.
- 39 SD Die Pflegerin ist geduldig, weil sie/er warten kann.
LD Die Pflegerin kann noch hoffen und ist geduldig, weil sie/er warten kann.
- 30 SD Die Polin ist verlobt, weil sie/er verliebt ist.
LD Die Polin schwebt auf Wolken und ist verlobt, weil sie/er verliebt ist.
- 41 SD Die Politikerin ist klug, weil sie/er gelernt hat.
LD Die Politikerin wird sehr gefürchtet und ist klug, weil sie/er gelernt hat.
- 42 SD Die Prinzessin war munter, weil sie/er Schlaf bekam.
LD Die Prinzessin kam bester Laune und war munter, weil sie/er Schlaf bekam.
- 43 SD Die Professorin ist anwesend, weil sie/er Besprechungen hat.
LD Die Professorin wirkt sehr gestresst und ist anwesend, weil sie/er Besprechungen hat.
- 44 SD Die Rentnerin ist wach, weil sie/er Kaffee trank.
LD Die Rentnerin hat schon aufgeräumt und ist wach, weil sie/er Kaffee trank.
- 45 SD Die Reporterin ist verreist, weil sie/er Entspannung sucht.
LD Die Reporterin hat alles aufgegeben und ist verreist, weil sie/er Entspannung sucht.
- 46 SD Die Schneiderin ist froh, weil sie/er Stoff kaufte.
LD Die Schneiderin beginnt zu arbeiten und ist froh, weil sie/er Stoff kaufte.
- 47 SD Die Schülerin hat geschwänzt, weil sie/er faul war.
LD Die Schülerin bekam heute Angst und hat geschwänzt, weil sie/er faul war.
- 48 SD Die Schwedin wird auftreten, weil sie/er Klavier spielt.
LD Die Schwedin ist sehr musikalisch und wird auftreten, weil sie/er Klavier spielt.
- 49 SD Die Schwester ist wütend, weil sie/er geärgert wurde.
LD Die Schwester schreit wieder laut und ist wütend, weil sie/er geärgert wurde.
- 50 SD Die Sekretärin ist verärgert, weil sie/er Überstunden macht.
LD Die Sekretärin schimpft heute laut und ist verärgert, weil sie/er Überstunden macht.
- 51 SD Die Sklavin ist hungrig, weil sie/er wenig isst.
LD Die Sklavin hat kein Geld und ist hungrig, weil sie/er wenig isst.
- 52 SD Die Spielerin ist arm, weil sie/er viel verliert.
LD Die Spielerin muss jetzt aufhören und ist arm, weil sie/er viel verliert.
- 53 SD Die Stewardess ist arbeitslos, weil sie/er Flugangst bekam.
LD Die Stewardess wurde plötzlich entlassen und ist arbeitslos, weil sie/er Flugangst bekam.
- 54 SD Die Studentin ist nervös, weil sie/er Prüfungen hat.
LD Die Studentin wird heute befragt und ist nervös, weil sie/er Prüfungen hat.
- 55 SD Die Tante ist akkurat, weil sie/er Ordnung mag.
LD Die Tante putzt sehr viel und ist akkurat, weil sie/er Ordnung mag.
- 56 SD Die Tochter ist krank, weil sie/er angesteckt wurde.
LD Die Tochter kauft schnell Medizin und ist krank, weil sie/er angesteckt wurde.

- 57 SD Die Touristin ist besorgt, weil sie/er krank ist.
LD Die Touristin muss nun ruhen und ist besorgt, weil sie/er krank ist.
- 58 SD Die Witwe muss weinen, weil sie/er traurig ist.
LD Die Witwe ist sehr verzweifelt und muss weinen, weil sie/er traurig ist.
- 59 SD Die Zeugin ist ängstlich, weil sie/er bedroht wird.
LD Die Zeugin muss versteckt werden und ist ängstlich, weil sie/er bedroht wird.
- 60 SD Die Zigeunerin ist beweglich, weil sie/er viel tanzt.
LD Die Zigeunerin wirkt sehr anmutig und ist beweglich, weil sie/er viel tanzt.
- 61 SD Der Abiturient ist schnell, weil er/sie laufen kann.
LD Der Abiturient hat viel trainiert und ist schnell, weil er/sie laufen kann.
- 62 SD Der Anwalt schläft schlecht, weil er/sie beunruhigt ist.
LD Der Anwalt wurde selbst verklagt und schläft schlecht, weil er/sie beunruhigt ist.
- 63 SD Der Arzt ist überarbeitet, weil er/sie Patienten betreut.
LD Der Arzt hat keine Zeit und ist überarbeitet, weil er/sie Patienten betreut.
- 64 SD Der Bengel ist langsam, weil er/sie verletzt ist.
LD Der Bengel humpelt schon länger und ist langsam, weil er/sie verletzt ist.
- 65 SD Der Boxer ist stolz, weil er/sie gefeiert wird.
LD Der Boxer hat gestern gewonnen und ist stolz, weil er/sie gefeiert wird.
- 66 SD Der Bruder ist sportlich, weil er/sie viel trainiert.
LD Der Bruder kann hoch springen und ist sportlich, weil er/sie viel trainiert.
- 67 SD Der Chef war spät, weil er/sie verschlafen hat.
LD Der Chef trank schwarzen Kaffee und war spät, weil er/sie verschlafen hat.
- 68 SD Der Chirurg ist ernst, weil er/sie gerade operiert.
LD Der Chirurg muss Ruhe haben und ist ernst, weil er/sie gerade operiert.
- 69 SD Der Clown ist bunt, weil er/sie verkleidet ist.
LD Der Clown lacht sehr laut und ist bunt, weil er/sie verkleidet ist.
- 70 SD Der Dichter ist poetisch, weil er/sie Gedichte schreibt.
LD Der Dichter trinkt sehr gern und ist poetisch, weil er/sie Gedichte schreibt.
- 71 SD Der Diener ist anerkannt, weil er/sie fleißig ist.
LD Der Diener verdient jetzt mehr und ist anerkannt, weil er/sie fleißig ist.
- 72 SD Der Direktor ist dick, weil er/sie viel isst.
LD Der Direktor mag kaum laufen und ist dick, weil er/sie viel isst.
- 73 SD Der Engländer ist errötet, weil er/sie schüchtern ist.
LD Der Engländer ist schnell beschämt und ist errötet, weil er/sie schüchtern ist.
- 74 SD Der Fahrer ist gefährlich, weil er/sie getrunken hat.
LD Der Fahrer sitzt im Auto und ist gefährlich, weil er/sie getrunken hat.
- 75 SD Der Fischer ist beruhigt, weil er/sie angeln kann.
LD Der Fischer hat viel Freude und ist beruhigt, weil er/sie angeln kann.
- 76 SD Der Freund ist neugierig, weil er/sie Gerüchte hörte.
LD Der Freund schreibt alles auf und ist neugierig, weil er/sie Gerüchte hörte.
- 77 SD Der Gatte ist schläfrig, weil er/sie nachts wacht.
LD Der Gatte ist sehr angespannt und ist schläfrig, weil er/sie nachts wacht.
- 78 SD Der General ist interessiert, weil er/sie Projekte hat.
LD Der General kauft viel ein und ist interessiert, weil er/sie Projekte hat.
- 79 SD Der Geselle ist unachtsam, weil er/sie müde ist.
LD Der Geselle macht einen Fehler und ist unachtsam, weil er/sie müde ist.
- 80 SD Der Häftling ist pfffig, weil er/sie flüchten konnte.
LD Der Häftling ist endlich frei und ist pfffig, weil er/sie flüchten konnte.
- 81 SD Der Häuptling ist kriegerisch, weil er/sie gewinnen will.
LD Der Häuptling greift bald an und ist kriegerisch, weil er/sie gewinnen will.
- 82 SD Der Herr ist reich, weil er/sie geizig ist.
LD Der Herr ist sehr unbeliebt und ist reich, weil er/sie geizig ist.
- 83 SD Der Hirte ist zuverlässig, weil er/sie Schafe hütet.
LD Der Hirte ist sehr tierlieb und ist zuverlässig, weil er/sie Schafe hütet.
- 84 SD Der Ingenieur ist unerfahren, weil er/sie jung ist.
LD Der Ingenieur kann viel anpacken und ist unerfahren, weil er/sie jung ist.
- 85 SD Der Jäger ist ordentlich, weil er/sie suchen hasst.
LD Der Jäger kam spät zurück und ist ordentlich, weil er/sie suchen hasst.
- 86 SD Der Jongleur ist verschnupft, weil er/sie erkältet ist.
LD Der Jongleur hat einen Husten und ist verschnupft, weil er/sie erkältet ist.

- 87 SD Der Journalist ist großzügig, weil er/sie Fotos hat.
LD Der Journalist ist sehr charmant und ist großzügig, weil er/sie Fotos hat.
- 88 SD Der Kamerad ist bescheiden, weil er/sie Freunde hat.
LD Der Kamerad ist sehr beliebt und ist bescheiden, weil er/sie Freunde hat.
- 89 SD Der Kapitän kennt Länder, weil er/sie viel segelt.
LD Der Kapitän weiß sehr viel und kennt Länder, weil er/sie viel segelt.
- 90 SD Der Knecht ist dünn, weil er/sie kaum isst.
LD Der Knecht geht jetzt schlafen und ist dünn, weil er/sie kaum isst.
- 91 SD Der Koch ist dickköpfig, weil er/sie egoistisch ist.
LD Der Koch ist schnell beleidigt und ist dickköpfig, weil er/sie egoistisch ist.
- 92 SD Der Kommissar ist effizient, weil er/sie arbeiten muss.
LD Der Kommissar muss schnell schreiben und ist effizient, weil er/sie arbeiten muss.
- 93 SD Der Laborant ist schüchtern, weil er/sie fremd ist.
LD Der Laborant arbeitet oft allein und ist schüchtern, weil er/sie fremd ist.
- 94 SD Der Mann ist geschickt, weil er/sie viel übt.
LD Der Mann hat viel Talent und ist geschickt, weil er/sie viel übt.
- 95 SD Der Narr lebt sehr mächtig, weil er/sie reich ist.
LD Der Minister wird schnell zornig und ist mächtig, weil er/sie reich ist.
- 96 SD Der Monteur ist tatkräftig, weil er/sie bald verweist.
LD Der Monteur packt schnell zu und ist tatkräftig, weil er/sie bald verweist.
- 97 SD Der Narr ist verrückt, weil er/sie Unsinn treibt.
LD Der Narr lebt sehr gefährlich und ist verrückt, weil er/sie Unsinn treibt.
- 98 SD Der Neffe schleckt Eis, weil er/sie Süßes mag.
LD Der Neffe kann gut genießen und schleckt Eis, weil er/sie Süßes mag.
- 99 SD Der Onkel kauft Süßes, weil er/sie Geschenke braucht.
LD Der Onkel ist sehr beschäftigt und kauft Süßes, weil er/sie Geschenke braucht.
- 100 SD Der Opa ist zerstreut, weil er/sie alt ist.
LD Der Opa vergisst fast alles und ist zerstreut, weil er/sie alt ist.
- 101 SD Der Patient hustet viel, weil er/sie zuviel raucht.
LD Der Patient ist noch unvernünftig und hustet viel, weil er/sie zuviel raucht.
- 102 SD Der Pfarrer trägt schwarz, weil er/sie Gottesdienst hält.
LD Der Pfarrer redet sehr viel und trägt schwarz, weil er/sie Gottesdienst hält.
- 103 SD Der Philosoph ist schlau, weil er/sie Pläne hat.
LD Der Philosoph kann hinterhältig sein und ist schlau, weil er/sie Pläne hat.
- 104 SD Der Pianist ist einsam, weil er/sie viel reist.
LD Der Pianist fährt wieder weg und ist einsam, weil er/sie viel reist.
- 105 SD Der Pirat ist betrunken, weil er/sie heute feiert.
LD Der Pirat torkelt heute sehr und ist betrunken, weil er/sie heute feiert.
- 106 SD Der Polizist wirkt autoritär, weil er/sie Uniformen trägt.
LD Der Polizist ist sehr distanziert und wirkt autoritär, weil er/sie Uniformen trägt.
- 107 SD Der Prinz ist eitel, weil er/sie hübsch ist.
LD Der Prinz wirkt oft eingebildet und ist eitel, weil er/sie hübsch ist.
- 108 SD Der Professor ist beschäftigt, weil er/sie Arbeit hat.
LD Der Professor kauft schnell ein und ist beschäftigt, weil er/sie Arbeit hat.
- 109 SD Der Punker ist auffällig, weil er/sie provozieren will.
LD Der Punker hat bunte Haare und ist auffällig, weil er/sie provozieren will.
- 110 SD Der Richter ist verweist, weil er/sie Termine hat.
LD Der Richter nimmt selten Urlaub und ist verweist, weil er/sie Termine hat.
- 111 SD Der Ritter ist verletzt, weil er/sie gekämpft hat.
LD Der Ritter muss versorgt werden und ist verletzt, weil er/sie gekämpft hat.
- 112 SD Der Sänger ist bekannt, weil er/sie fantastisch singt.
LD Der Sänger verdient sehr viel und ist bekannt, weil er/sie fantastisch singt.
- 113 SD Der Schauspieler ist erfolgreich, weil er/sie ehrgeizig ist.
LD Der Schauspieler arbeitet sehr lange und ist erfolgreich, weil er/sie ehrgeizig ist.
- 114 SD Der Schlosser ist schmutzig, weil er/sie viel arbeitet.
LD Der Schlosser repariert alles schnell und ist schmutzig, weil er/sie viel arbeitet.
- 115 SD Der Schüler lernt fleißig, weil er/sie Klausuren schreibt.
LD Der Schüler kann fast alles und lernt fleißig, weil er/sie Klausuren schreibt.
- 116 SD Der Soldat ist kräftig, weil er/sie Fitness betreibt.
LD Der Soldat joggt immer weit und ist kräftig, weil er/sie Fitness betreibt.

- 117 SD Der Spieler ist enttäuscht, weil er/sie verloren hat.
 LD Der Spieler wurde richtig abgezockt und ist enttäuscht, weil er/sie verloren hat.
 118 SD Der Spion ist gespannt, weil er/sie Aufträge hat.
 LD Der Spion ist sehr aufgeregt und ist gespannt, weil er/sie Aufträge hat.
 119 SD Der Vater ist ungeduldig, weil er/sie Ruhe braucht.
 LD Der Vater schimpft sehr laut und ist ungeduldig, weil er/sie Ruhe braucht.
 120 SD Der Zauberer ist witzig, weil er/sie Humor hat.
 LD Der Zauberer hat einen Trick und ist witzig, weil er/sie Humor hat.

Thing as antecedent

- 1 SD Die Ampel ist aus, weil sie/er defekt ist.
 LD Die Ampel muss repariert werden und ist aus, weil sie/er defekt ist.
 2 SD Die Banane ist matschig, weil sie/er überreif ist.
 LD Die Banane schmeckt sehr seltsam und ist matschig, weil sie/er überreif ist.
 3 SD Die Binde ist rötlich, weil sie/er blutig ist.
 LD Die Binde muss gewaschen werden und ist rötlich, weil sie/er blutig ist.
 4 SD Die Blume ist verblüht, weil sie/er vertrocknet ist.
 LD Die Blume muss entfernt werden und ist verblüht, weil sie/er vertrocknet ist.
 5 SD Die Bluse ist schön, weil sie/er seiden ist.
 LD Die Bluse wird oft getragen und ist schön, weil sie/er seiden ist.
 6 SD Die Brille ist durchsichtig, weil sie/er gläsern ist.
 LD Die Brille wurde endlich geputzt und ist durchsichtig, weil sie/er gläsern ist.
 7 SD Die Butter ist zerlaufen, weil sie/er erwärmt wurde.
 LD Die Butter schmeckt schon ranzig und ist zerlaufen, weil sie/er erwärmt wurde.
 8 SD Die Couch ist bequem, weil sie/er gepolstert ist.
 LD Die Couch ist schon besetzt und ist bequem, weil sie/er gepolstert ist.
 9 SD Die Decke ist und erreichbar, weil sie/er hoch ist.
 LD Die Decke muss gestrichen werden und ist unerreichbar, weil sie/er hoch ist.
 10 SD Die Fabrik ist zerstört, weil sie/er unmodern ist.
 LD Die Fabrik muss restauriert werden und ist zerstört, weil sie/er unmodern ist.
 11 SD Die Flasche ist ausgelaufen, weil sie/er undicht war.
 LD Die Flasche ist sehr klebrig und ist ausgelaufen, weil sie/er undicht war.
 12 SD Die Frisur ist furchtbar, weil sie/er misslungen ist.
 LD Die Frisur muss verändert werden und ist furchtbar, weil sie/er misslungen ist.
 13 SD Die Frucht ist gesund, weil sie/er Vitamine hat.
 LD Die Frucht wird oft empfohlen und ist gesund, weil sie/er Vitamine hat.
 14 SD Die Gabel hat Gewicht, weil sie/er metall ist.
 LD Die Gabel ist schön geformt und hat Gewicht, weil sie/er metall ist.
 15 SD Die Galerie ist interessant, weil sie/er Werke zeigt.
 LD Die Galerie wird viel besucht und ist interessant, weil sie/er Werke zeigt.
 16 SD Die Gitarre ist harmonisch, weil sie/er gestimmt wurde.
 LD Die Gitarre klingt sehr schön und ist harmonisch, weil sie/er gestimmt wurde.
 17 SD Die Glocke ist laut, weil sie/er groß ist.
 LD Die Glocke ist sehr schwer und ist laut, weil sie/er groß ist.
 18 SD Die Halle ist riesig, weil sie/er vergrößert wurde.
 LD Die Halle wird oft genutzt und ist riesig, weil sie/er vergrößert wurde.
 19 SD Die Heizung ist heiß, weil sie/er an ist.
 LD Die Heizung wärmt jetzt endlich und ist heiß, weil sie/er an ist.
 20 SD Die Hose ist schmutzig, weil sie/er schlammig ist.
 LD Die Hose muss gewaschen werden und ist schmutzig, weil sie/er schlammig ist.
 21 SD Die Jacke ist warm, weil sie/er gefüttert ist.
 LD Die Jacke ist sehr kuschelig und ist warm, weil sie/er gefüttert ist.
 22 SD Die Karte ist gezinkt, weil sie/er markiert wurde.
 LD Die Karte wird oft versteckt und ist gezinkt, weil sie/er markiert wurde.
 23 SD Die Kathedrale ist kalt, weil sie/er ungeheizt ist.
 LD Die Kathedrale ist riesig groß und ist kalt, weil sie/er ungeheizt ist.
 24 SD Die Kerze brennt hell, weil sie/er angezündet wurde.
 LD Die Kerze ist schon klein und brennt hell, weil sie/er angezündet wurde.
 25 SD Die Kette ist teuer, weil sie/er antik ist.
 LD Die Kette wird jetzt ausgestellt und ist teuer, weil sie/er antik ist.

- 26 SD Die Klinke ist lila, weil sie/er lackiert wurde.
LD Die Klinke ist nun klebrig und ist lila, weil sie/er lackiert wurde.
- 27 SD Die Kneipe ist voll, weil sie/er beliebt ist.
LD Die Kneipe ist gut besucht und ist voll, weil sie/er beliebt ist.
- 28 SD Die Krawatte ist schick, weil sie/er modern ist.
LD Die Krawatte wird oft getragen und ist schick, weil sie/er modern ist.
- 29 SD Die Krone funkelt hell, weil sie/er golden ist.
LD Die Krone ist sehr bekannt und funkelt hell, weil sie/er golden ist.
- 30 SD Die Limonade ist kalt, weil sie/er gekühlt wurde.
LD Die Limonade ist schön erfrischend und ist kalt, weil sie/er gekühlt wurde.
- 31 SD Die Maschine ist laut, weil sie/er wackelig steht.
LD Die Maschine springt ein bisschen und ist laut, weil sie/er wackelig steht.
- 32 SD Die Nase trieft stark, weil sie/er verschnupft ist.
LD Die Nase ist sehr verstopft und trieft stark, weil sie/er verschnupft ist.
- 33 SD Die Perle ist wertvoll, weil sie/er selten ist.
LD Die Perle wird gut bewacht und ist wertvoll, weil sie/er selten ist.
- 34 SD Die Rakete fliegt los, weil sie/er gestartet wurde.
LD Die Rakete hat laut geknallt und fliegt los, weil sie/er gestartet wurde.
- 35 SD Die Salbe ist lindernd, weil sie/er Schmerzen stillt.
LD Die Salbe ist sehr hilfreich und ist lindernd, weil sie/er Schmerzen stillt.
- 36 SD Die Schachtel ist deformiert, weil sie/er zerdrückt wurde.
LD Die Schachtel war sehr schön und ist deformiert, weil sie/er zerdrückt wurde.
- 37 SD Die Scheibe ist klar, weil sie/er geputzt wurde.
LD Die Scheibe ist richtig blank und ist klar, weil sie/er geputzt wurde.
- 38 SD Die Schere ist scharf, weil sie/er geschliffen wurde.
LD Die Schere ist wieder spitz und ist scharf, weil sie/er geschliffen wurde.
- 39 SD Die Schiene wird gewechselt, weil sie/er porös ist.
LD Die Schiene ist sehr gefährlich und wird gewechselt, weil sie/er porös ist.
- 40 SD Die Schule ist geschlossen, weil sie/er renoviert wird.
LD Die Schule ist sehr alt und ist geschlossen, weil sie/er renoviert wird.
- 41 SD Die Schüssel wird weggeworfen, weil sie/er Risse hat.
LD Die Schüssel ist nun aussortiert und wird weggeworfen, weil sie/er Risse hat.
- 42 SD Die Skulptur ist anmutig, weil sie/er filigran ist.
LD Die Skulptur ist fein gearbeitet und ist anmutig, weil sie/er filigran ist.
- 43 SD Die Socke riecht schlecht, weil sie/er ungewaschen ist.
LD Die Socke ist etwas muffig und riecht schlecht, weil sie/er ungewaschen ist.
- 44 SD Die Sohle ist löchrig, weil sie/er durchgelaufen ist.
LD Die Sohle ist sehr porös und ist löchrig, weil sie/er durchgelaufen ist.
- 45 SD Die Sonne blendet stark, weil sie/er grell ist.
LD Die Sonne scheint heute kräftig und blendet stark, weil sie/er grell ist.
- 46 SD Die Stange ist schwer, weil sie/er bleiern ist.
LD Die Stange wird kaum getragen und ist schwer, weil sie/er bleiern ist.
- 47 SD Die Straße ist glatt, weil sie/er vereist ist.
LD Die Straße ist sehr gefährlich und ist glatt, weil sie/er vereist ist.
- 48 SD Die Stufe ist schwierig, weil sie/er hoch ist.
LD Die Stufe wird oft gemieden und ist schwierig, weil sie/er hoch ist.
- 49 SD Die Suppe ist scharf, weil sie/er gewürzt wurde.
LD Die Suppe schmeckt sehr gut und ist scharf, weil sie/er gewürzt wurde.
- 50 SD Die Tablette ist ungesund, weil sie/er giftig ist.
LD Die Tablette muss gemieden werden und ist ungesund, weil sie/er giftig ist.
- 51 SD Die Tafel ist beschrieben, weil sie/er genutzt wurde.
LD Die Tafel muss geputzt werden und ist beschrieben, weil sie/er genutzt wurde.
- 52 SD Die Tasche ist praktisch, weil sie/er übersichtlich ist.
LD Die Tasche ist sehr groß und ist praktisch, weil sie/er übersichtlich ist.
- 53 SD Die Tasse ist leer, weil sie/er ausgetrunken wurde.
LD Die Tasse muss gespült werden und ist leer, weil sie/er ausgetrunken wurde.
- 54 SD Die Tinte ist verschmiert, weil sie/er feucht war.
LD Die Tinte ist schön blau und ist verschmiert, weil sie/er feucht war.
- 55 SD Die Treppe ist anstrengend, weil sie/er Stufen hat.
LD Die Treppe muss gebohrt werden und ist anstrengend, weil sie/er Stufen hat.

- 56 SD Die Truhe ist braun, weil sie/er hölzern ist.
LD Die Truhe ist sehr schön und ist braun, weil sie/er hölzern ist.
- 57 SD Die Tür ist offen, weil sie/er kaputt ist.
LD Die Tür muss repariert werden und ist offen, weil sie/er kaputt ist.
- 58 SD Die Uhr ist genau, weil sie/er gestellt wurde.
LD Die Uhr geht ganz präzise und ist genau, weil sie/er gestellt wurde.
- 59 SD Die Vase ist kaputt, weil sie/er gefallen ist.
LD Die Vase muss entsorgt werden und ist kaputt, weil sie/er gefallen ist.
- 60 SD Die Wunde ist schmerzend, weil sie/er tief ist.
LD Die Wunde ist leider entzündet und ist schmerzend, weil sie/er tief ist.
- 61 SD Der Anzug ist unbequem, weil er/sie steif ist.
LD Der Anzug kratzt sehr stark und ist unbequem, weil er/sie steif ist.
- 62 SD Der Apfel ist süß, weil er/sie reif ist.
LD Der Apfel ist schön saftig und ist süß, weil er/sie reif ist.
- 63 SD Der Arm ist träge, weil er/sie belastet wurde.
LD Der Arm ist heute kraflos und ist träge, weil er/sie belastet wurde.
- 64 SD Der Bach ist geschützt, weil er/sie rein ist.
LD Der Bach muss behütet werden und ist geschützt, weil er/sie rein ist.
- 65 SD Der Balkon ist verboten, weil er/sie brüchig ist.
LD Der Balkon muss gestützt werden und ist verboten, weil er/sie brüchig ist.
- 66 SD Der Ballon schwebt oben, weil er/sie leicht ist.
LD Der Ballon schaukelt ein wenig und schwebt oben, weil er/sie leicht ist.
- 67 SD Der Berg ist anstrengend, weil er/sie hoch ist.
LD Der Berg ist oben eisig und ist anstrengend, weil er/sie hoch ist.
- 68 SD Der Boden ist rutschig, weil er/sie gebohnt wurde.
LD Der Boden ist noch feucht und ist rutschig, weil er/sie gebohnt wurde.
- 69 SD Der Braten ist schmackhaft, weil er/sie gar ist.
LD Der Braten ist knusprig braun und ist schmackhaft, weil er/sie gar ist.
- 70 SD Der Computer ist defekt, weil er/sie vervirt ist.
LD Der Computer muss ausgedockt werden und ist defekt, weil er/sie vervirt ist.
- 71 SD Der Faden ist zerrissen, weil er/sie überspannt wurde.
LD Der Faden wurde dünn gesponnen und ist zerrissen, weil er/sie überspannt wurde.
- 72 SD Der Fernseher ist gut, weil er/sie neu ist.
LD Der Fernseher ist technisch aktuell und ist gut, weil er/sie neu ist.
- 73 SD Der Füller ist pink, weil er/sie auffallen soll.
LD Der Füller schreibt sehr gut und ist pink, weil er/sie auffallen soll.
- 74 SD Der Garten ist verwildert, weil er/sie unbewohnt ist.
LD Der Garten soll verkauft werden und ist verwildert, weil er/sie unbewohnt ist.
- 75 SD Der Gürtel ist eng, weil er/sie fest ist.
LD Der Gürtel sitzt sehr stramm und ist eng, weil er/sie fest ist.
- 76 SD Der Hals ist geschwollen, weil er/sie entzündet ist.
LD Der Hals schmerzt sehr stark und ist geschwollen, weil er/sie entzündet ist.
- 77 SD Der Herd ist heiß, weil er/sie an ist.
LD Der Herd ist sehr schmutzig und ist heiß, weil er/sie an ist.
- 78 SD Der Käse wird flüssig, weil er/sie erwärmt wurde.
LD Der Käse ist schön geschmeidig und wird flüssig, weil er/sie erwärmt wurde.
- 79 SD Der Kaffee ist stark, weil er/sie aufwecken soll.
LD Der Kaffee ist endlich fertig und ist stark, weil er/sie aufwecken soll.
- 80 SD Der Keller ist unheimlich, weil er/sie dunkel ist.
LD Der Keller ist sehr kalt und ist unheimlich, weil er/sie dunkel ist.
- 81 SD Der Kiosk ist unbesetzt, weil er/sie geschlossen ist.
LD Der Kiosk muss schnell weg und ist unbesetzt, weil er/sie geschlossen ist.
- 82 SD Der Knopf ist ab, weil er/sie lose war.
LD Der Knopf ist sehr klein und ist ab, weil er/sie lose war.
- 83 SD Der Korb ist biegsam, weil er/sie elastisch ist.
LD Der Korb wird oft genutzt und ist biegsam, weil er/sie elastisch ist.
- 84 SD Der Kuchen ist kalorienreich, weil er/sie sahnig ist.
LD Der Kuchen schmeckt sehr süß und ist kalorienreich, weil er/sie sahnig ist.
- 85 SD Der Mantel ist blau, weil er/sie gefärbt wurde.
LD Der Mantel ist wie neu und ist blau, weil er/sie gefärbt wurde.

- 86 SD Der Mond ist unsichtbar, weil er/sie verdeckt ist.
LD Der Mond ist heute verschwunden und ist unsichtbar, weil er/sie verdeckt ist.
- 87 SD Der Mund ist rot, weil er/sie durchblutet ist.
LD Der Mund kann fantastisch lachen und ist rot, weil er/sie durchblutet ist.
- 88 SD Der Nagel ist rostig, weil er/sie nass war.
LD Der Nagel muss gewechselt werden und ist rostig, weil er/sie nass war.
- 89 SD Der Pickel ist lästig, weil er/sie schmerzhaft ist.
LD Der Pickel muss behandelt werden und ist lästig, weil er/sie schmerzhaft ist.
- 90 SD Der Pudding ist lecker, weil er/sie schokoladig ist.
LD Der Pudding muss gekühlt werden und ist lecker, weil er/sie schokoladig ist.
- 91 SD Der Rasen ist grün, weil er/sie beregnet wurde.
LD Der Rasen wurde frisch gemäht und ist grün, weil er/sie beregnet wurde.
- 92 SD Der Reifen ist luftdicht, weil er/sie geflickt wurde.
LD Der Reifen kann genutzt werden und ist luftdicht, weil er/sie geflickt wurde.
- 93 SD Der Ring ist unauffindbar, weil er/sie verschwunden ist.
LD Der Ring ist sehr wertvoll und ist unauffindbar, weil er/sie verschwunden ist.
- 94 SD Der Reis ist weich, weil er/sie verkocht wurde.
LD Der Reis ist leider klebrig und ist weich, weil er/sie verkocht wurde.
- 95 SD Der Rucksack ist schwer, weil er/sie gepackt ist.
LD Der Rucksack wurde schnell geflickt und ist schwer, weil er/sie gepackt ist.
- 96 SD Der Saft ist lecker, weil er/sie frisch ist.
LD Der Saft kostet sehr viel und ist lecker, weil er/sie frisch ist.
- 97 SD Der Samen keimt schon, weil er/sie gesetzt wurde.
LD Der Samen ist noch klein und keimt schon, weil er/sie gesetzt wurde.
- 98 SD Der Scheinwerfer leuchtet wieder, weil er/sie repariert wurde.
LD Der Scheinwerfer wird wieder genutzt und leuchtet wieder, weil er/sie repariert wurde.
- 99 SD Der Schirm ist verkäuflich, weil er/sie genäht wurde.
LD Der Schirm ist wieder repariert und ist verkäuflich, weil er/sie genäht wurde.
- 100 SD Der Schornstein wird abgerissen, weil er/sie störend ist.
LD Der Schornstein ist richtig hässlich und wird abgerissen, weil er/sie störend ist.
- 101 SD Der Schrank ist morsch, weil er/sie Würmer hat.
LD Der Schrank quietscht immer laut und ist morsch, weil er/sie Würmer hat.
- 102 SD Der Schuh ist kaputt, weil er/sie alt ist.
LD Der Schuh ist nun löchrig und ist kaputt, weil er/sie alt ist.
- 103 SD Der Sessel ist schwer, weil er/sie groß ist.
LD Der Sessel ist sehr bequem und ist schwer, weil er/sie groß ist.
- 104 SD Der Tag ist mild, weil er/sie sonnig ist.
LD Der Tag kann nun beginnen und ist mild, weil er/sie sonnig ist.
- 105 SD Der Tank ist voll, weil er/sie gefüllt wurde.
LD Der Tank rostet ein wenig und ist voll, weil er/sie gefüllt wurde.
- 106 SD Der Tee ist schlecht, weil er/sie bitter ist.
LD Der Tee wird schnell kalt und ist schlecht, weil er/sie bitter ist.
- 107 SD Der Teller ist zerbrochen, weil er/sie runter fiel.
LD Der Teller ist schön bemalt und ist zerbrochen, weil er/sie runter fiel.
- 108 SD Der Topf ist unbrauchbar, weil er/sie Löcher hat.
LD Der Topf ist total leer und ist unbrauchbar, weil er/sie Löcher hat.
- 109 SD Der Tunnel ist dunkel, weil er/sie lang ist.
LD Der Tunnel wird kaum beleuchtet und ist dunkel, weil er/sie lang ist.
- 110 SD Der Wagen kostet viel, weil er/sie neu ist.
LD Der Wagen ist sehr schnell und kostet viel, weil er/sie neu ist.
- 111 SD Der Wald ist kahl, weil er/sie gerodet wurde.
LD Der Wald ist praktisch tot und ist kahl, weil er/sie gerodet wurde.
- 112 SD Der Wasserhahn tropft laut, weil er/sie undicht ist.
LD Der Wasserhahn muss repariert werden und tropft laut, weil er/sie undicht ist.
- 113 SD Der Wecker ist gestellt, weil er/sie klingeln soll.
LD Der Wecker tickt sehr laut und ist gestellt, weil er/sie klingeln soll.
- 114 SD Der Wein schmeckt gut, weil er/sie trocken ist.
LD Der Wein wird gern getrunken und schmeckt gut, weil er/sie trocken ist.
- 115 SD Der Whiskey ist angenehm, weil er/sie innen wärmt.
LD Der Whiskey wird oft gekauft und ist angenehm, weil er/sie innen wärmt.

- 116 SD Der Zahn ist hässlich, weil er/sie gelb ist.
LD Der Zahn muss gezogen werden und ist hässlich, weil er/sie gelb ist.
- 117 SD Der Zaun ist hoch, weil er/sie schützen soll.
LD Der Zaun wurde extra verstärkt und ist hoch, weil er/sie schützen soll.
- 118 SD Der Zettel ist verschwunden, weil er/sie winzig war.
LD Der Zettel ist sehr wichtig und ist verschwunden, weil er/sie winzig war.
- 119 SD Der Zopf ist kurz, weil er/sie abgeschnitten wurde.
LD Der Zopf ist schön blond und ist kurz, weil er/sie abgeschnitten wurde.
- 120 SD Der Zug ist spät, weil er/sie angehalten wurde.
LD Der Zug ist sehr voll und ist spät, weil er/sie angehalten wurde.

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Curriculum Vitae

- 1976 Born in Burg, Germany
- 1996 – 2001 Study of Psychology, Otto-von-Guericke University, Magdeburg
- 1997-1998 Student Research Assistant, Department of Social Psychology, Otto-von-Guericke University, Magdeburg
- 1998-2001 Student Research Assistant, Department of Neuropsychology, Otto-von-Guericke University, Magdeburg.
- 2001 M.A. Psychology. Thesis: Amyotrophic Lateral Sclerosis (ALS) and possible extra-motor effects investigated by ERP and neuropsychological tests. Supervisors: Prof. T. F. Münte, Prof. H.-J. Heinze
- 2001-2004 PhD student, Department of Neurocognition, Faculty of Psychology, Maastricht University. Semantics, syntax and working memory during pronoun resolution investigated by temporal and spatial neuroimaging. Supervisors: R. Goebel, B. M. Jansma.
- 2004 – present Researcher, Department of Neurocognition, Faculty of Psychology Maastricht University