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The processing of complex syntax in early childhood

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I dedicate this thesis to Lidia Strotseva.

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Preface

At the age of about two years, children start to produce their first two- and three-word combinations (Guasti, 2002; Szagun, 2006). In the following period, a rapid development in the acquisition of syntax takes place (Klann-Delius, 1999). One of the fundamental challenges of this development is the ability to detect and interpret the interplay of linguistic features that encode the relationships between participants of a sentence. The current study aims to examine the role of syntactic and semantic features for interpretation of complex sentences at the very beginning of this developmental phase. It focuses on the comprehension of complex sentences in German-acquiring children between 2;0 and 3;11 years.

The study addresses three questions. First, it explores whether children are able to identify the grammatical cues of case marking at a perceptual level. Second, it examines the question as to how young learners weight the cues of case marking and animacy when assigning thematic roles to verb arguments, and how this ability develops between the age of 2 and 3. Third, the study seeks to find the neuronal correlates of thematic role assignment in children and adults.

The dissertation is organized as follows. Chapter 1 provides a general review of theoretical concepts and of relevant sentence comprehension models. Chapter 2 is devoted to the description of behavioral and neurobiological methods that are used in the dissertation. Chapter 3 answers the question of children's ability to auditorily discriminate between relevant case markers, as assessed using the *mismatch negativity* (MMN) paradigm. The chapter consists of a review of the main MMN findings in developmental perspective and four sections that describe experiments on discriminative abilities of children (Experiments 1a–1c) and adults (Experiment 1d). Chapter 4 sets out to answer the question how the cues of case marking and animacy are used for offline behavioral sentence interpretation.

It contains an overview of behavioral studies that assessed the role of syntactic and semantic features for sentence comprehension in early childhood. The following two sections of Chapter 4 describe two experiments that evaluate the behavioral response in 2-year-old (Experiment 2a) and 3-year-old (Experiment 3a) children. Chapter 5 assesses the online processing of case marking and animacy in sentential context from electrophysiological perspective. It provides a review of the relevant studies on the neural correlates of syntactic and semantic processing in children and adults, which is followed by a summary of experiments with children (Experiments 3a–3b) and adults (Experiment 3c). Chapter 6 summarizes the results of the experiments and provides a general discussion of the main findings.

1 Linguistic background

1.1 Thematic roles and their realization

The relations between arguments of a sentence and their relation to the action, that is, the question of *who is doing what to whom* in a sentence, are discussed in terms of thematic roles[1] in linguistics. A set of eight thematic roles is known, namely Agent, Patient, Theme, Goal, Beneficiary, Experiencer, Instrument, and Location (Butt, 2006). A complex picture arises, however, when considering various theoretical accounts that suggest different thematic role constellations (e.g., Case Grammar (Fillmore, 1968, 1971), Lexical Decomposition Grammar (Wunderlich, 2006), Lexical-Functional Syntax (Bresnan, 2001); for a review, see Primus (2009)).

One way to resolve a problem of multiple thematic hierarchies is the concept of Proto-roles used by Dowty (1991). Two generalized semantic roles are defined in this approach, namely the role of *Proto-Agent* and the role of *Proto-Patient*. Each of them is associated with a number of semantic features. The role of Proto-Agent entails volitional action, sentience/perception, movement, causation and existence independently of the action that is encoded by the verb. Proto-Patient, in contrast, undergoes a change of state, is casually affected by another participant, is stationary relative to another participant and does not exist independently of an event (Dowty, 1991, p. 172ff.). This dichotomy shows an asymmetric dependency pattern: Proto-Agent is not dependent on the Proto-Patient, whereas Proto-Patient is dependent on the Proto-Agent (Primus, 1999).

In German, thematic relations can be expressed by different means. Essentially, this function is hold by morphological coding (case marking). However, case marking does not always unambiguously inform about thematic properties of the argument. In such cases, animacy, argument position in a sentence, and subject-verb agreement may define the thematic status of a sentence argument. Information cues that are relevant for the current study will be briefly discussed in next sections.

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[1] These roles are also termed *semantic roles*, *case roles*, and *theta roles* in various theories.

Case

According to the core definition, case “is a system of marking dependent nouns for the type of relationship they bear to their heads” (Blake, 2001). German has a system of four cases: nominative, accusative, dative, and genitive. The case is mostly realised through the morphological marking on determiners, including articles as well as interrogative, demonstrative and possessive pronouns. To illustrate this, Table 1.1.1 represents the suffixation paradigm of several German determiners, including definite article.

Table 1.1.1. The inflection paradigm of some German determiners.

	Singular			**Plural**
	masc.	***neut.***	***fem.***	
Nominative	-er	-e	-es	-e
Accusative	-en	-e	-es	-e
Dative	-em	-er	-es	-er
Genitive	-es	-er	-es	-er

Note: These include definite article, demonstrative pronoun *dies*- ‘this’, indefinite pronoun *manch*- ‘some’, interrogative pronoun *welch*- ‘which’, etc. Note a vowel change in the neuter masculine and accusative forms: *das* instead of *des*.

German nominal inflection has two patterns that are described as ‘strong’ and ‘weak’ declension (Sommerfeldt, Starke, & Hackel, 1998). The strong declension, as in (1.1a), does not require any changes in noun stem in singular masculine accusative form, so that an external marker is necessary for case assignment. The singular genitive form is realized through the suffix *-(e)s*. The singular dative form can contain the suffix *–e*. The weak declension requires a suffix *–en* in all singular masculine non-nominative forms, as in (1.1b).

(1.1a)	*der Baum* ‘the.NOM[2] tree’	*den Baum* ‘the.ACC tree’	*des Baum(es)* ‘the.GEN tree’	*dem Baum(e)* ‘the.DAT tree’
(1.1b)	*der Bär* ‘the.NOM bear’	*den Bären* ‘the.ACC bear’	*des Bären* ‘the.GEN bear’	*dem Bären* ‘the.DAT bear’

In active German sentence, the thematic role of agent is coded by the nominative-marked form. The patient that is physically affected by the agent is realized

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[2] The following case abbreviations are used in this dissertation: NOM, nominative; ACC, accusative; GEN, genitive; DAT, dative.

as a direct object which is preferably marked by accusative case (Primus, 2012)[3]. Thus, in canonical sentence (1.2a), *the policeman* is the agent, and *the cyclist* is the patient.

(1.2a) *Der Polizist beobachtet den Radfahrer.*
the.NOM policeman watches the.ACC cyclist
'The policeman is watching the cyclist.'

(1.2b) *Den Radfahrer beobachtet der Polizist.*
the.ACC cyclist watches the.NOM policeman
'The policeman is watching the cyclist.'

From a pragmatic viewpoint, the policeman is the *topic* of the utterance (1.2a), whereas the rest of the sentence is the *comment/focus*. Topic is what a sentence is about; comment is what is predicated about the topic (Gundel & Fretheim, 2008, p. 176). Topic and comment constitute an information structure of the sentence. The thematic roles of agent and patient do not change if the information structure is changed as in (1.2b), that is, the cyclist becomes the topic of the sentence. Corpus-based studies have shown that topicalized clauses are less frequent in comparison to canonical clauses in German. For example, in a sample of main declarative sentences with two arguments (*n* = 311) in the study by Bader and Haussler (2010), 254 clauses (81.7%) were subject-first structures and 57 clauses (18.3%) were object-first structures.

Behavioral developmental studies have shown that children at the age of two are not able to use case marking for thematic interpretation of topicalized sentences as in (1.2b). The consequent use of case marking could be observed only between the age of five and seven, although children did not show adult-like behavior even at this age (Dittmar, Abbot-Smith, Lieven, & Tomasello, 2008; Knoll, Obleser, Schipke, Friederici, & Brauer, 2012; Primus & Lindner, 1994; Schaner-Wolles, 1989; Schipke, Knoll, Friederici, & Oberecker, 2012). Thus, the functional meaning of case marking is acquired late in childhood (for a review of behavioral studies, see section *The acquisition of case* in Chapter 4).

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[3] The thematic role of patient can be also encoded by nominative case marking in German, e.g., in case of ergative verbs, as in *Heute ist in wenigen Minuten das Speiseeis geschmolzen.* 'The ice cream has melted in a few minutes today.' (Primus, 2012, p. 35).

Animacy

All languages, including German, appear to discriminate between animate and inanimate entities (Comrie, 1989; Frawley, 1992). Relationship between animacy and the probability of the noun to be a subject or an agent of the sentence was reflected in Silverstein's Animacy Hierarchy (Silverstein, 1986). The simplified scale *human* > *animate* > *inanimate* (Aissen, 2003) can be directly mapped to the order of sentence constituents. On the one hand, this mapping is associated with the linear ordering of constituents in sentence, according to which an animate entity is located before an inanimate entity. The corroborating evidence comes from numerous corpus-based, production and ERP studies (Bock, Loebell, & Morey, 1992; Paczynski & Kuperberg, 2011; Rosenbach, 2005; Snider & Zaenen, 2006). For example, a corpus study by Kempen and Harbusch (2004) showed the animate-first linearization preference in German subordinate clauses.

On the other hand, animacy is related to the assignment of thematic roles (Kempen & Harbusch, 2004; Paczynski & Kuperberg, 2011). Dowty (1991) describes the Proto-Agent as capable of volitional actions which implies that the ideal agent is prototypically animate. The patient role is mostly associated with inanimate entity (see also Comrie, 1989; Hopper & Thompson, 1980). The association between thematic roles and animacy has been confirmed in a number of behavioural studies (e.g., Ferreira, 2003; Mak, Vonk, & Schriefers, 2002, 2006; Traxler, Morris, & Seely, 2002). Congruency between the animacy status of a noun and thematic role has been shown to facilitate the processing of ambiguous and unambiguous complex sentences in adults (see section *Neurophysiological correlates of animacy in adults* in Chapter 5.1). Animacy contrast in sentence (i.e., the presence of two noun phrases with different animacy status) was argued to be the primary cue to sentence interpretation in early childhood (Chan, Lieven, & Tomasello, 2009; Lindner, 2003).

Word order

The roles of agent and patient can be marked by the position of the argument in sentence. English heavily relies on word order to mark thematic roles, that is, initial argument of an active sentence is interpreted as an agent (MacWhinney, Bates, & Kliegl, 1984). Likewise, the order Subject-Verb-Object (SVO) is a canonical word order in German active declarative sentences, although other combinations, such as OVS, OSV, VOS, and VSO, can occur due to grammatical and pragmatic reasons.

Despite of the variety of word order options in German, research into processing of ambiguous and complex sentences has shown a preference to analyze the first argument as a subject/an agent (Bader & Meng, 1999; Frisch, Schlesewsky, Saddy, & Alpermann, 2002; Graben, Saddy, Schlesewsky, & Kurths, 2000; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Schlesewsky, Bornkessel, & Frisch, 2003; Schlesewsky, Fanselow, Kliegl, & Krems, 2000; Schriefers, Friederici, & Kuhn, 1995). There are several explanations for the subject-first preference (for a review, see Bornkessel-Schlesewsky & Schlesewsky, 2009a). First, the processing of object-first structure can be more demanding in terms of working memory because initial object (the so called *filler*) should be stored in memory until the argument-verb linking takes place and the so called *gap* for the filler can be found. Initial subject does not produce such a dependency due to the possible intransitive reading (Gibson, 1998). Second, frequency of use in speech context may also play a role. As mentioned above, the proportion of object-first structures is lower compared to subject-first structures (Bader & Haussler, 2010). Probabilistic parsing accounts (e.g., Crocker & Brants, 2000; Jurafsky, 1996) suggest that the interpretation of constructions that are more likely to occur is preferred over interpretation of rare constructions (for discussion, see also Bornkessel, Schlesewsky, & Friederici, 2002b). Third, the subject-first preference has been explained via relational minimality (Bornkessel & Schlesewsky, 2006). This principle entails that “only required dependencies and relations are created” (Bornkessel & Schlesewsky, 2006, p. 790). Only minimal structures are assigned if nothing explicitly indicates the contrary. Following this principle, the initial argument is analyzed as the sole argument of an intransitive event, that is, as a subject.

Behavioral experiments have shown that German-speaking adults primarily rely on case marking during assignment of thematic roles (Kempe &

MacWhinney, 1999; MacWhinney et al., 1984). If the case marking is ambiguous (e.g., both arguments are marked with feminine form *die*), speakers tend to use other features, including word order, animacy and agreement to assign thematic roles. The strength of these cues was argued to depend on several factors which are specified in the so called *Competition model* (MacWhinney, 1987, 2002; MacWhinney & Bates, 1989). The neurobiological basis of cue-based argument interpretation has been described by the *Extended argument dependency model* (eADM; Bornkessel-Schlesewsky & Schlesewsky, 2009a; Bornkessel & Schlesewsky, 2006). The Extended argument dependency model grew from the *Neurocognitive model of auditory sentence comprehension* by Friederici (2002, 2011, 2012a). The following sections briefly present the main principles of these three models.

1.2 Models of language comprehension

The competition model

According to the Competition model (MacWhinney, 1987, 2002), sentence processing involves a direct weighted form-to-function mapping that is based on a number of information types, or cues. These cues include morphosyntactic, lexical and prosodic features of the input, such as case marking, agreement, animacy, word order, and stress pattern.

The language-specific weight of the cue is determined by a *validity*. A highly valid cue has the largest effect on sentence interpretation in language. For example, word order is the cue of the highest validity in English. Cue validity is determined by four dimensions (MacWhinney, 2002):

- Task frequency: The strength of a cue depends on the frequency of the task. For example, the task to define the agent of the sentence is accomplished every time when a transitive verb is encountered.
- Cue availability: The more available the cue, the more weight it has. The available cue can be used if it is contrastive. For example, in the sentence *The cat chases the dog.*, the noun-verb agreement cue is available, but it is

not contrastive because both arguments are singular. In the sentence *The cat chases the dogs.*, the noun-verb agreement cue is both available and contrastive. Cue availability is a ratio of the cases in which the cue is available over the total number of cues in a given task (Bates & MacWhinney, 1987, p. 164).

- Simple reliability: The cue is reliable if it points to the correct functional choice. Cue reliability is a ratio of the cases in which the cue leads to correct decision over the number of cases in which it is available (Bates & MacWhinney, 1987, p. 164).
- Conflict reliability: In certain contexts, one cue is more reliable than another. For example, in Dutch, an NP preceding a modal verb is usually interpreted as an agent. However, if the NP is an accusative-marked pronoun, the cue of case marking dominates over the word order cue (MacWhinney, 1997).

Generally, the cue validity is a product of cue availability and cue reliability. The Competition model predicts that the order of acquisition of grammatical devices is determined by the relative cue validity. This order is therefore hypothesized to be language-specific and cannot be seen as a universal developmental schedule (Bates & MacWhinney, 1987, 1989).

The effect of cue validity during language acquisition is constrained by two factors. On the one hand, children might not be ready to acquire a complex form because they are not able to assimilate the underlying functions of particular cues (*functional readiness*). For example, Italian children definitely hear various stress patterns encoding agent and patient in non-canonical sentence, but are not able to interpret these patterns until the age of nine (Bates & MacWhinney, 1987). The Competition model suggests that the late reliance on the prosodic cue is due to the missing understanding of pragmatic reasons for the complex discourse structures. On the other hand, the processing of a cue might be associated with high cognitive costs (*cue cost*). Some cues may be very hard to perceive due to the subtle acoustic differences. For example, nominative and accusative case-markers in Hungarian differ only in the final consonant /mokus – mokust/ (Bates

& MacWhinney, 1987; MacWhinney, Pléh, & Bates, 1985). It is possible that the acoustic contrast between them is not clearly perceived by children.

Moreover, cues might be difficult to store, especially if the assignment of thematic roles and the cue are separated by several information entities. The cues of high assignability, or *local* cues, can be used as soon as they are perceived (Bates & MacWhinney, 1987, p. 180). For example, inflectional suffixes in Turkish and Serbo-Croatian were suggested to facilitate sentence processing strategies (Ammon & Slobin, 1979). In contrast, the cues of low assignability, or *global* cues, such as word order cue in English and Italian, were argued to be costly to handle during sentence interpretation (see also Johnston & Slobin, 1979; Kail & Charvillat, 1988).

Furthermore, based on the fact that functions may be expressed by multiple forms, the Competition model proposes a principle of *coalition-as-prototype*. One of the examples of coalition is the organization of 'sentence subject' that can be understood as a many-to-many mapping of forms, such as nominative case marking, preverbal position, agreement with verb, and functions, such as an agent of the transitive action and a topic (Bates & MacWhinney, 1987). The model predicts that the processing of sentences in which multiple cues cooperate in pointing to one function is easier for children. Conflicting cues lead to difficulties in sentence comprehension. Adults and children choose different strategies when processing such sentences. While adults follow the cues with the highest validity, children rely on the cues with the highest availability (Bates & MacWhinney, 1989).

Studies within the framework of the Competition model have shown that case marking is a fully determinate cue in adult sentence interpretation in German. On the strength scale, it was followed by the cues of animacy, agreement and word order (MacWhinney et al., 1984). German-acquiring children come to understand the reliability of case marking by the age of seven (Dittmar et al., 2008). Animacy and word order were argued to be alternative cues of sentence interpretation in 2- and 3-year-old children (Lindner, 2003; Schipke et al., 2012)[4].

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[4] The detailed overview of these experiments is presented in sections *The acquisition of case* and *Animate-inanimate distinction in developmental perspective* of Chapter 4.

The neurocognitive model of auditory sentence comprehension

The neurocognitive model of auditory sentence comprehension (Friederici, 2002, 2011, 2012a) proposes a hierarchically organized processing that includes three phases (Figure 1.2.1).

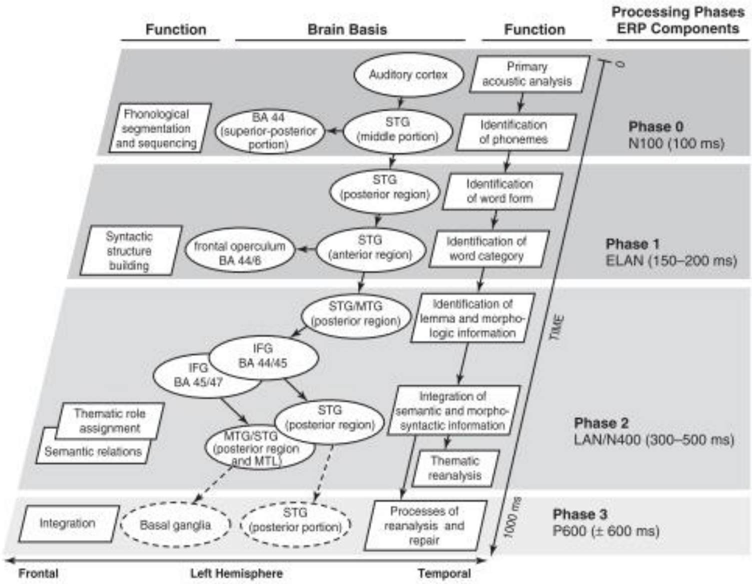

Figure 1.2.1. The neurocognitive model of auditory sentence comprehension. Adapted from Friederici (2006).

These phases are preceded by Phase 0, during which phonological process take place. In Phase 1 (100–300 ms), the initial syntactic structure is build based on word category information. Mismatch between perceived and expected word category elicits an early left anterior negativity (ELAN).

Phase 2 (300–500 ms) is associated with the processing of lexico-semantic and morphosyntactic features as well as with the processes of thematic assignment. Problems of semantic integration are reflected by N400, a negative deflection that peaks around 400 ms after the word onset. N400 is also evoked by thematic anomalies (Friederici & Frisch, 2000). A left anterior negativity (LAN) is elicited during this phase in response to morphosyntactic violation. Phases 1 and 2 are argued to involve temporal and inferior brain structures.

During Phase 3 (500–1000 ms), different types of information, including syntactic, semantic and thematic information, are integrated. The processes of reanalysis and/or repair that are reflected by P600, take place. The centro-parietal late positivity occurs in response to morphosyntactic errors, whereas the processing of complex sentences is related to a fronto-central P600 component (Friederici, Hahne, & Saddy, 2002). The processes of Phase 3 are suggested to involve temporal areas and the basal ganglia.

The extended argument dependency model

Similarly to the neurocognitive model of sentence comprehension by Friederici, the extended argument dependency model (eADM) suggests a hierarchically organized sentence processing that can be described in three phases (Figure 1.2.2).

During Phase 1 (TEMPLATE ACTIVATION/SELECTION), basic constituent structure is built based on word category information. No argument interpretation takes place at this stage. The processing difficulties during the initial phase are related to ELAN.

In Phase 2, argument interpretation is initialized based on the set of relational features. Relations between the arguments and between argument and verb are established. This phase is divided into two sub-phases: Phase 2a and Phase 2b.

During Phase 2a, the relevant relational features are extracted from the input. These include morphological and positional features of the noun phrase (NP), as well as form, voice (active/passive), agreement information and lexical argument representation (logical structure, LS) of the verb.

Phase 2b reflects relational processing of these features. In the step COMPUTE PROMINENCE, the prominence information of NP is assigned. The term *prominence* accounts for all types of information that are used to establish an Actor-Undergoer hierarchy[5], including case marking, argument position, animacy,

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[5] *Agent-patient hierarchy* in our nomenclature.

definiteness and person. These information types are organized as a series of prominence scales, e.g., nominative > accusative, argument 1 > argument 2, animate > inanimate (Bornkessel-Schlesewsky & Schlesewsky, 2009b). The scales serve to define the probability of the argument to be an actor. The weighting of the information types is language-specific. Mismatch between computed prominence information and the features of the encountered item elicits an N400 (Frisch & Schlesewsky, 2001; Roehm, Schlesewsky, Bornkessel, Frisch, & Haider, 2004). Similarly, the mismatch between activated template and relational feature can produce a *scrambling negativity* during the COMPUTE PROMINENCE step (Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998). In the step COMPUTE LINKING, the logical structure of the verb is linked to the arguments or argument hierarchies. The mismatch between the verb and the Actor/Undergoer role (generalized semantic role, GR) during the COMPUTE LINKING step may result in a LAN effect. The failure to map the roles of Actor/Undergoer to the argument is related to the early positivity P345 (Bornkessel, Schlesewsky, & Friederici, 2002a, 2003b). Agreement mismatch produces an N400 during this stage.

During Phase 3, the GENERALIZED MAPPING, that is, the final argument interpretation takes place. It involves information from other domains such as world knowledge, frequency of occurrence, pitch accents and stress patterns. These features are processed in REPAIR and WELL-FORMEDNESS steps that are reflected by late positivities.

Importantly, the neurobiological model attempts to account for the basic property of brain, that is, hierarchical processing of information (Bornkessel-Schlesewsky & Schlesewsky, 2014a). The Competition model does not require hierarchical processing but describes competing motivations during sentence comprehension. The common ground of the Competition model and the eADM model is their account for different information types (cues, prominence features) that are involved into establishing form-to-function mappings across languages.

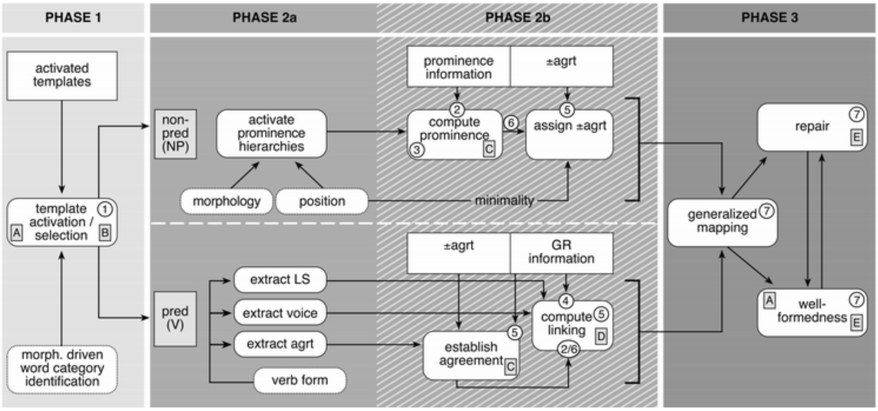

Figure 1.2.2. The extended argument dependency model, eADM. LS, logical structure. GR, generalized semantic role. ERP correlates of the individual processing steps: 1, ELAN; 2, N400; 3, scrambling negativity; 4, P345; 5, LAN; 6, P600; 7, late positivity. Neuroanatomical correlates of individual processing steps: A, deep frontal operculum; B, anterior superior temporal gyrus; C, inferior frontal gyrus, pars opercularis; D, posterior superior temporal sulcus; E, basal ganglia. Adapted from Bornkessel and Schlesewsky (2006).

1.3 The present study

Experimental studies on the use of case marking within the Competition model have suggested that, despite of the cue's high strength in the grammatical system of German, children are able to rely on it only by the age of seven. One might speculate that children abandon a morphosyntactic strategy due to the high cognitive costs that are associated with the processing of case markers. As has been shown above, the paradigm of German case marking is characterized by a high level of polysemy and acoustic similarity. Therefore, the first part of the current dissertation focuses on the question of *identification*. It explores whether 2- and 3-year-old children are able to acoustically discriminate between case markers. Specifically, two forms of German definite article are examined to answer this question, namely the nominative masculine singular form *der* and the accusative masculine singular form *den*. These forms unambiguously indicate thematic roles in declarative transitive sentences. Children's discrimination abilities are compared to those of adults who are known to correctly use case forms for sentence interpretation. The auditory discrimination abilities in both age groups are assessed using the method of event-related potentials in an attention-independent paradigm.

The second part of the dissertation seeks to examine the *functional* question of how pre-schoolers use the articles *der* and *den* for sentence interpretation. As pointed above, the adult-like use of case marking develops late in childhood. Instead, children may rely on other available cues, such as animacy contrast and word order, when interpreting *who is doing what to whom*. We will present a behavioural study which aims to explore whether the lexical-semantic constraint of animacy facilitates the interpretation of complex sentences in children. It also traces the developmental course of the use of case marking and animacy between 2;0 and 3;11 years of age.

Finally, neurophysiological models, such as the eADM model, suggest that the form-to-function mappings that involve the processing of morphosyntactic and semantic cues have *neurophysiological correlates*, including a scrambling/topicalization negativity and modulations of an N400 response. Mismatches between thematic role assignments, induced by conflicting cues, have been shown to produce a distinct brain response in adults. So far, the neurophysiological underpinnings of the processing of syntactic complexity have been explored in 3-year-old children (Mahlstedt, 2008; Schipke et al., 2012). The third part of the dissertation aims to assess the neuronal correlates of sentence interpretation in 2- and 3-year-olds and in adults. It will also relate the behavioural data to the event-related measures of sentence processing in children.

2 General methodology

Two experimental methods were used in the current study. Behavioral response to complex sentences was assessed using a picture-matching task. Auditory discrimination between determiners *der* and *den*, as well as neural correlates of sentence processing were investigated using the method of event-related potentials. The main principles of these methods are very briefly presented in the following sections.

2.1 Picture-matching task

Performance in the picture-matching task (also, forced-choice pointing) allows to assess children's comprehension of sentences without an explicit verbal response. In this task, participant hears a sentence and looks at two pictures (e.g., Figure 2.1.1). One picture matches the sentence, whereas another does not. The participant is asked to point to the picture that corresponds to the sentence she hears. In contrast to preferential looking paradigms, the task produces an unambiguous binary measure that can be easily analyzed (Ambridge & Lieven, 2011).

Figure 2.1.1. Example of an experimental item in picture-matching task. On hearing the sentence *Der Esel schiebt den Fuchs.* 'The donkey pulls the fox.' participants are asked to point to the picture that corresponds to the utterance.

The task has been successfully used in the studies on syntax acquisition both with pictures and cartoon animations with children of 2;0 years and above (Arunachalam & Waxman, 2010; Dittmar et al., 2008; Dittmar, Abbot-Smith, Lieven, & Tomasello, 2011; Fernandes, Marcus, Di Nubila, & Vouloumanos, 2006; Legendre, Barriere, Goyet, & Nazzi, 2010; Maguire, Hirsh-Pasek, Golinkoff, & Brandone, 2008; Noble, Rowland, & Pine, 2011). Most of these studies evaluated the results via comparison to chance level. The chance level is defined mathematically, that is, the chance level of 50% is taken if the choice is made between two pictures. If the accuracy of performance significantly exceeds the chance level, participants are assumed to act systematically. One shortcoming of the picture-matching task is that it does not account for baseline preferences that a child may have for one picture over another (Ambridge & Lieven, 2011, p. 95).

2.2 Event-related potentials

Like many other methods that require an overt behavioral response, also the results of the picture-matching task do not only reflect the pure comprehension abilities of the participants. Children's performance is most likely confounded with the ability to concentrate on the task, that is, with attention and memory demands. Electroencephalography (EEG) does not always require an overt behavioral response and can be used to study attention-independent processes with non-responsive or pre-linguistic populations.

Electroencephalographic recordings reflect the activity of neuronal populations that includes two types of potentials, namely, action potentials and post-synaptic potentials. While action potentials are short-term changes of polarity that fire the impulse only if the sodium threshold is reached in the cell (all-or-none principle), post-synaptic potentials lead to the graded change of electrical activity at the cell membrane. Summation of post-synaptic potentials makes EEG recording possible (Luck, 2014). It measures the voltage difference between the recording electrodes and the reference electrode that are imbedded into EEG cap.

In order to study the brain activity that is evoked by specific cognitive processes, stimulus events are presented repeatedly during EEG recording. The voltage changes that are time-locked to the repeated events are averaged. Brain activity unrelated to the processing of stimuli is assumed to be reduced via the averaging process that results in event-related potentials (ERP). ERPs are considered to be a direct measure of brain activity unfolded over time. A voltage change that reflects a specific neural and psychological process is called an ERP component (Kappenman & Luck, 2011). ERP components are described in terms of their amplitude (in µV), polarity (positive/negative), latency (in ms), scalp distribution and functional significance (Luck, 2014; Männel, 2008; Rugg & Coles, 1995).

Averaging is not the only processing step that is required to obtain ERP. Prior to the averaging procedure, the EEG data is subjected to a number of preprocessing procedures that aim to identify, remove or correct artefactual activity. Artefacts arise from the sources other than brain, for example, from the movements of eye that functions as an electrical dipole (Rugg & Coles, 1995; for classification of artefact types, see Talsma & Woldorff, 2005). Epochs containing eye movements and blinks can be removed from the EEG. However, artefact removal in child data may lead to the considerable reduction of a number of critical epochs. Standardized artefacts, such as eye blinks and horizontal eye movements, may be corrected using several methods, e.g., regression analysis in both time and frequency domain (Gratton, Coles, & Donchin, 1983; Kenemans, Molenaar, Verbaten, & Slangen, 1991) and Independent Component Analysis (ICA; Jung et al., 2000). In the current EEG studies, both methods were used to automatically correct eye-related artefacts (for details, see Appendix D).

3 Auditory processing of determiners *der* and *den*

3.1 Introduction

The ability to auditorily differentiate between speech sounds is crucial for language comprehension. Speech-sound discrimination develops during the first year of life (Cheour-Luhtanen et al., 1996). This ability builds on pattern detection skills and statistical strategies, as well as general cognitive competence and social factors (Kuhl, 2004). Abnormal development of the speech-sound discrimination has been shown to relate to language disorders, such as dyslexia and specific language impairment (for a review of clinical studies, see Bishop, 2007).

The accuracy of the auditory processing both for speech and non-speech input can be objectively measured using the electrophysiological marker of automatic change detection *mismatch negativity* (MMN; Näätänen, 2001). MMN is a negative deflection of the difference wave that is obtained by subtracting the brain response to a *standard* (frequently presented) sound from a *deviant* (infrequently presented) sound in so-called oddball paradigms (Figure 3.1.1).

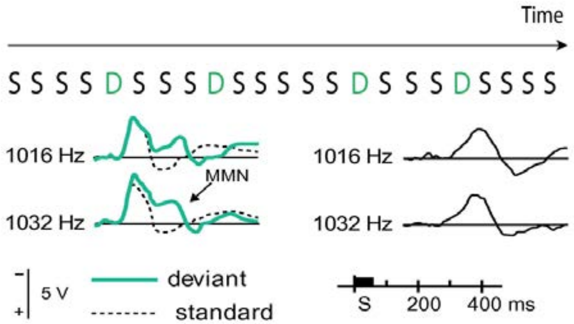

Figure 3.1.1. Classical oddball paradigm. Top: Frequent stimuli (standards, S) and infrequent stimuli (deviants, D). Bottom left: Event-related potentials to standard 1000-Hz tone (in dashed black) and deviant tones of different frequencies (in green) at the Fz electrode site. Bottom right: Difference waves at the Fz electrode, as calculated by subtraction of the ERP response to the standard from the ERP response to the deviant. Adapted from Näätänen, Paavilainen, Rinne, and Alho (2007); Sams, Paavilainen, Alho, and Näätänen (1985).

In mastoid- and nose-referenced EEG recordings, the MMN is distributed in frontal and central scalp areas (Näätänen et al., 2007). In nose-referenced recordings, MMN inverts its polarity at the electrodes below the Sylvian fissure. This allows to discriminate the automatic MMN from the more controlled N2b response that remains negative when the tip of the nose is used for a reference electrode (Kujala, Tervaniemi, & Schröger, 2007).

The sensitivity of the MMN response to acoustic change has been shown to correspond to the thresholds observed in behavioural discrimination tasks (Näätänen et al., 2007). Advantageously, the MMN can be elicited when experiment participants do not focus attention on the stimulus material, which allows for the study of MMN in young-aged groups (Näätänen, 2000).

In the forthcoming, the models accounting for the neural mechanisms of the MMN response are presented. This is followed by an overview of the MMN literature on the processing of linguistic stimuli at phonological, lexical, semantic and morphosyntactic levels. Next section briefly summarizes developmental patterns of the mismatch negativity response. Finally, we review several other ERP components that have been elicited in oddball paradigms along with the mismatch negativity.

Neural mechanisms of MMN

The underlying neural systems of the MMN have been discussed in light of several models, including memory-trace (Näätänen, Jacobsen, & Winkler, 2005; Näätänen et al., 2007), adaptation (Jääskeläinen et al., 2004; May & Tiitinen, 2010), model adjustment (Winkler, Karmos, & Näätänen, 1996), novelty detection (Escera & Corral, 2007; Tiitinen, May, Reinikainen, & Näätänen, 1994), and prediction error hypotheses (Garrido, Kilner, Stephan, & Friston, 2009; Wacongne, Changeux, & Dehaene, 2012). Three models that received the most attention in research are briefly introduced in the following paragraphs.

The ***memory-trace account*** explains MMN as a neurophysiological response to the change of incoming repetitive stimuli. In this view, MMN is a result of discrepancy between the established memory representation of the standard stimulus and the encountered deviant (Näätänen et al., 2005; Näätänen et al., 2007). The mismatch response is generated by supratemporal and frontal cerebral sources, where the former one is associated with sensory memory and change detection, and the latter one with an involuntary attention switch (Doeller et al., 2003; Giard, Perrin, Pernier, & Bouchet, 1990; Opitz, Rinne, Mecklinger, von Cramon, & Schröger, 2002; Rinne, Alho, Ilmoniemi, Virtanen, & Näätänen, 2000).

The memory-trace account assumes that the mismatch negativity can be only elicited if a deviant stimulus is preceded by a series of standard stimulus items that form a memory representation. In such conditions, deviants and standards are often presented at different frequencies and thus differ in degree of refractoriness of the neuronal populations they activate. The resulting discrepancy between the exogenous responses to the standards and to the deviants might contribute to the negative deflection at early latencies, as reflected by the N1 component, a fronto-central negativity peaking between 50–200 ms after the onset of the auditory stimulus (Näätänen & Picton, 1987). However, the memory-trace model consistently separates N1 and MMN in terms of latency and duration (Winkler, Tervaniemi, & Näätänen, 1997), scalp distribution (Giard et al., 1995), cerebral generators (discussed below), and elicitation conditions (Atienza & Cantero, 2001; Näätänen, 1992).

The memory-trace explanation found support in the studies that were able to reduce the effects of the N1 by using a controlled protocol, as it was done by Schröger and Wolff (1996). In their experiment on detection of sound location change, Schröger and Wolff (1996) introduced an additional condition, in which standard items were substituted by random sounds. Similar to standards and deviants, the replaced sounds differed to each other in the azimuth distance. Acoustically, the differences between replaced sounds and deviants were either equal or larger than the differences between standards and deviants. Therefore, the neural response to the replaced items in control condition was less refractory than the response to the deviant, thus reducing the N1 confound (Horváth et al., 2008; Jacobsen & Schröger, 2001; Schröger, 2007). A MEG study by Maess, Jacobsen, Schröger, and Friederici (2007) used the same controlled protocol to explore the MMN response to tone frequency deviation. The authors were able to separate the sensory component from the cognitive activity on temporal dimension. While the earlier part of the N1 component between 105–125 ms was associated with sensory activity, later peak between 170–200 ms was related to the cognitive part of the MMN. As indicated by the individual moving dipole approach, these activities were overlapping in spatial domain both being localized bilaterally within Heschl's gyrus.

Spatial segregation of MMN and N1 has been supported by a number of studies using dipole modeling in MEG (Hari, Rif, Tiihonen, & Sams, 1992; Korzyukov et al., 1999; Rosburg, 2003; Rosburg, Haueisen, & Kreitschmann-Andermahr, 2004) and EEG data (Scherg, Vajsar, & Picton, 1989), as well as using functional magnetic resonance imaging (fMRI; Opitz, Schröger, & von Cramon, 2005). These studies have shown that the generators of the MMN response are localized anterior to the generators of the N1 in superior temporal plane.

In contrast to the memory-based account, the ***adaptation model*** interprets the MMN as a latency and duration modulation of the N1 component (May & Tiitinen, 2010). In this view, cerebral response to stimulus deviation is considered to be a result of the refractoriness discrepancy or synaptic habituation. While the frequent repetition of standard items leads to adaptation and suppression of the corresponding neural cells in auditory cortex, infrequent deviant items are claimed to activate less suppressed neurons. The negative deflection thus results from the subtraction of the N1 response to the frequent sound from the N1 response to the infrequent sound. Therefore, MMN does not appear to be an independent component but a part of the N1 that is sensitive to the presentation rate of the stimulus (for a review, see Garrido et al., 2009; May & Tiitinen, 2010; Näätänen, 1990; Näätänen et al., 2005).

The adaptation account suggests the possibility to elicit an MMN-like response in the absence of the preceding repetitive stimulus, as it is presupposed by the memory-trace theory. In fact, such negativity was elicited in a study by Jääskeläinen et al. (2004), in which tone frequency 'novel' variants were presented with the fixed novel-to-novel sound interval of 3.5 s (Jääskeläinen et al., 2004;

Experiment 1). Their electrophysiological experiment consisted of two sessions (Figure 3.1.2).

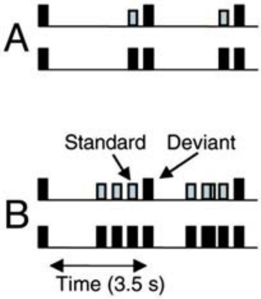

Figure 3.1.2. The experimental paradigm, used by Jääskeläinen et al. (2004). Upper panel: session A containing 'test' and 'control' blocks with single standards. Bottom panel: session B containing multiple standards. Adapted from Jääskeläinen et al. (2004).

Six blocks were presented in one session. Three of these blocks were 'test' blocks with one 'standard' tone presented 350 ms before the 'novel' sound. In the other three blocks, the frequency of the 'standard' and the 'novel' sound were identical. The other session contained blocks with two to four 'standard' sounds preceding the 'novel' sound (for the critical discussion of this study, see Näätänen et al. (2005). Furthermore, Jääskeläinen et al. (2004) differentiated between refractoriness effects in two N1 subcomponents (Loveless, Levanen, Jousmaki, Sams, & Hari, 1996). The adaptation effect was shown to be smaller for the late anterior negativity (N1a) peaking at 150 ms than for the early posterior negativity (N1p) peaking at 85 ms. According to Jääskeläinen et al. (2004), this spatiotemporal difference might have effect on the results of the current dipole modeling that has shown spatial segregation between MMN and N1.

The ability of the brain to detect the difference between standards and deviant items has been recently discussed as a product of regularity learning and active prediction of the incoming stimulus (Bendixen, SanMiguel, & Schröger, 2012; Friston, 2005; Garrido et al., 2009; Wacongne et al., 2012; Winkler, 2007). ***Predictive models*** suggest that mismatch negativity is a result of a discrepancy between the prediction generated by the brain on the basis of the acoustic environment and the current stimulus material. Specifically, Friston's neuroanatomical predictive model interprets the mismatch negativity as being based on perceptual inference and learning (Friston, 2005). This account proceeds from the assumption that the cerebral sensory system is organized hierarchically. The sensory input propagates in bottom-up manner. Prediction signals are formed at higher sensory levels and propagate in top-down manner to lower levels, where they suppress prediction error. The error signal, as produced by a mismatch between the prediction and the incoming sensory input, propagates to the higher levels where the prediction is adjusted. Efficient error suppression is possible due to the adjustment of connection strengths via synaptic plasticity. The reduction of the predictive error appears to be associated with the so called *repetition positivity,* a slow wave between 50–250 ms that increases in amplitude as a function of standard repetition (Baldeweg, 2007; Baldeweg, Klugman, Gruzelier, & Hirsch, 2004; Haenschel, Vernon, Dwivedi, Gruzelier, & Baldeweg, 2005; Schröger et al., 2014).

Predictive models of the mismatch response found support in a series of studies that used statistical modeling (Garrido et al., 2008; Lieder, Daunizeau, Garrido, Friston, & Stephan, 2013), as well as mismatch (S. Grimm & Schröger, 2007; Tervaniemi, Saarinen, Paavilainen, Danilova, & Näätänen, 1994) and omission response paradigms with tonal material (for review, see Bendixen et al., 2012; Todorovic, van Ede, Maris, & de Lange, 2011; Wacongne et al., 2011). In a very recent study, Bendixen, Scharinger, Strauss, and Obleser (2014) manipulated the predictability of speech segments in single-word and sentence contexts. Alternating German words *Lachs* [laks] and *Latz* [lats] with the cropped fragment *La*, the authors were able to elicit an omission mismatch negativity around 125–165 ms after the point of deviation, that is, the offset of the vowel. The cerebral sources of this response were reconstructed in left superior temporal and left angular gyri. These findings suggest that generation of auditory predictions is possible independently of the sources of predictability in speech stream.

MMN response to speech

Speech sounds and tones were shown to be processed differently in previous comparative studies (Csépe, 1995; Dehaene-Lambertz, 2000; Korpilahti, Krause, Holopainen, & Lang, 2001; Maurer, Bucher, Brem, & Brandeis, 2003; Paquette et al., 2013). For instance, the study by Čeponienė, Alku, Westerfield, Torki, and Townsend (2005) reported an earlier larger N1/P2 response to the non-speech stimuli and a larger N2/N4 response to speech trials in adults and school children. Linguistic stimuli were also shown to elicit a greater mismatch negativity at earlier latencies with cerebral sources being localized in the left hemisphere than the corresponding synthesized non-linguistic material (Maurer et al., 2003; Paquette et al., 2013; Shtyrov, Kujala, Palva, Ilmoniemi, & Näätänen, 2000). These differences were explained by different processing mechanisms for speech and non-speech stimuli. While linguistic material was claimed to be processed acoustically (at sensory level) and phonetically (at categorization level), non-linguistic material is processed only acoustically (Paquette et al., 2013; Tampas, Harkrider, & Hedrick, 2005). Similarly, speech sound discrimination was dominated by the left hemisphere in adults in the MEG study by Shtyrov et al. (2000). In contrast, complex non-speech stimuli were either associated with the right hemisphere dipole moments (for sounds with slow acoustic transitions), or with no hemispheric dominance (for sounds with rapid acoustic transitions). The existing long-memory traces for syllables, which were presumably maintained in the left hemisphere with linguistic experience, were argued to explain the hemispheric asymmetry.

The mismatch response to language-related stimuli was found to be modulated at phonological, lexical, semantic and morphosyntactic levels (Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007). In the following, the relevant MMN patterns are discussed in detail.

MMN to phonological contrasts

Stimulus-dependent amplitude shifts have been found in MMN studies on language-specific phonological repertoires. Specifically, the amplitude of the MMN appears to be greater for native-language phonetic contrasts in comparison to the response to the non-native categories (Näätänen, 2000; Näätänen et al., 2012). For example, in a study by Dehaene-Lambertz (1997), French speakers were presented with native French and non-native Hindi phonetic contrasts. The deviance was introduced either by within- or across-category consonant manipulation in syllables /ba/, /da/ and their frequency variants. In this experiment, only native across-category contrasts elicited a mismatch negativity peaking at 280 ms. Näätänen et al. (1997) conducted a similar experiment using vowel contrasts with Finnish and Estonian speakers. Finnish participants showed a significantly attenuated mismatch response to the Estonian deviant /õ/ that was not present in their native language. Sharma and Dorman (2000) manipulated Hindi pre-voicing in syllables /ba/ and /pa/. Hindi and English native speakers were presented with standard items with short voice onset time (VOT) and deviants with long VOT. Both groups elicited an N1 component, but only Hindi speakers elicited a robust MMN since pre-voicing is phonemic category in their language.

As has been reported in infant studies, the ability to discriminate between native-language phonemic categories, as reflected by mismatch response, develops by the age of 12 months. This was shown in the experiments by Cheour, Čeponienė, et al. (1998) who presented Finnish and Estonian infants with the standard phoneme /e/ and two deviants, the Finnish /ö/ and the Estonian /õ/, as it was done with adult participants in the study by Näätänen et al. (1997). While Finnish 6-month-olds showed similar MMN both for Finnish and Estonian deviants, the same infants had a smaller amplitude to the Estonian vowel than to the Finnish vowel at the age of 12 months. Estonian 12-month-olds did not show differences between /ö/ and /õ/, since both of them belong to the phonological inventory of the Estonian language. These results indicated that the language-specific memory traces were developing in children in the first year of life. Such traces were also found in 3-month-old children in the study by Dehaene-Lambertz and Baillet (1998).

Furthermore, mismatch negativity was employed to explore the neuronal plasticity that accompanied the learning of new phonological categories both in adults and children (Näätänen, 2008). Six-hour speech-discrimination training resulted in significant change of MMN duration and the area under MMN wave even in participants that did not show improvement in behavioural task in the study by Kraus et al. (1995). In another study, English-speaking participants that were trained on identification of prevoiced labial stop sound showed an increased mismatch response to the VOT contrasts, including prevoiced alveolar stop that was not learned explicitly (Tremblay, Kraus, Carrell, & McGee, 1997). Fluent but non-native speakers were shown to produce an MMN response to the Finnish vowel contrasts that was comparable to the MMN in native speakers (Winkler et al., 1999). In the study by Cheour, Shestakova, Alku, Čeponienė, and Näätänen (2002), 3- to 6-year-old children acquired the ability to discriminate between non-native phonemes after two months of natural exposure to a foreign language. The development of phonological representations was reflected by the amplitude increase and latency decrease of the MMN response to the vowel contrasts of the foreign language. Finally, MMN-indexed learning effects were demonstrated in full-term new-borns that were exposed to 2.5–5 hours of vowel training during sleep (Cheour, Martynova, et al., 2002).

In sum, mismatch negativity studies on phonological processing indicate that the MMN is modulated by long-memory phonological representations that develop due to continuous and temporary exposure to linguistic environment.

MMN to lexical and semantic contrasts

As has been shown in the studies on phonological contrasts above, the mismatch response is modulated by language experience. At the lexical level, this relationship was supported by the studies that assessed the lexical enhancement effect of MMN. The effect was evident when the mismatch response to words was compared with that to pseudowords. In most of experiments of this kind, the MMN was greater to the deviant word than to the deviant non-word at around 150–180 ms after the point of physical deviation (Pulvermüller & Shtyrov, 2006). Moreover, the effect for the words was more frontally distributed in comparison to that for the pseudowords (Shtyrov & Pulvermüller, 2002). The enlargement of the MMN associated with the lexical word was replicated across several languages including German (Diesch, Biermann, & Luce, 1998), Chinese Mandarin (Gu et al., 2012), Finnish (Korpilahti et al., 2001; Pulvermüller et al., 2001; Pulvermüller, Shtyrov, Kujala, & Näätänen, 2004), English (Bakker, MacGregor, Pulvermüller, & Shtyrov, 2013; Shtyrov & Pulvermüller, 2002) and Spanish (Tavano et al., 2012). Among others, the lexical enhancement of the MMN amplitude was reported for the German item *ab* [ap], a short word that either modifies the meaning of the verb (as an adverb) or functions as a preposition

(Endrass, Mohr, & Pulvermüller, 2004). The reduced MMN to the contrasting non-word *ak* [ak] was found between 70–140 ms after the point of deviation, that is, 200 ms after stimulus onset. Comparable enhancement effects were reported in one of a few studies with children by Korpilahti et al. (2001). They examined the processing of tones, words and non-words in Finnish-speaking 4- to 7-year-olds. The enhancement effect could be observed within the latency range of the late MMN (lMMN) between 350–500 ms. Similar to adult studies, words elicited in preschool children a lMMN of greater amplitude and latency than pseudowords.

Several interpretations have been suggested for the mechanisms underlying the modulation of the mismatch response by lexicality. One account explains the MMN magnitude differences by the immediate access to the word-specific long-term memory traces (Pulvermüller, 1999; Shtyrov & Pulvermüller, 2007). Such long-term representations are formed by distributed *cell assemblies* that develop from the frequent co-activation of specific neurons. While pseudowords are not associated with specific distributed networks, meaningful words are represented by functional cortical units that activate entirely as soon as the word is recognized. MMN discrepancies thus result from the implicit access to lexical information encoded by word traces (Pulvermüller, 1999; Shtyrov, Hauk, & Pulvermüller, 2004).

An alternative model has been recently tested in a lexicality study by Tavano et al. (2012) who hypothesized a link between sensory trace and long-term trace matching. The authors suggested that both sensory memory and lexical access are operated by the mechanisms of the spectro-temporal point-wise comparison between the incoming stimulus and the predicted model (S. Grimm & Schröger, 2007). In their study, an intersyllabic salient gap was inserted into words and non-words, such that the stimulus material was presented in three conditions: no gap, 20-ms gap, and 120-ms gap. The MMN to deviant words was absent in fronto-central but enhanced over midline sites in 20-ms gap condition. The MMN to pseudowords was distributed in fronto-temporal scalp areas. According to the authors, the gap insertion only disturbed the long-term trace matching, whereas the spectro-temporal matching within sensory memory was not interrupted.

Hence, the spectro-temporal point-wise processing was argued to be the core of the dynamic MMN mechanism that bridge sensory and long-term memory.

Following the line of research into the effects of the long-term memory word traces, several studies showed that MMN was modulated by the occurrence frequency of the word in a specific language. A study by Alexandrov, Boricheva, Pulvermüller, and Shtyrov (2011) compared the mismatch response to Russian high-frequent *мир* [m'ir] 'peace, world' to low-frequent *мор* [mor] 'plague'. The MMN response to the high-frequent word was 1.3 μV greater at Fz and 56 ms earlier than that to the low-frequent word. Corroborating results were obtained for Finnish nouns (Shtyrov, Kimppa, Pulvermüller, & Kujala, 2011), English opaque compounds (MacGregor & Shtyrov, 2013), and Finnish derived and inflected words (Leminen, Leminen, Kujala, & Shtyrov, 2013). The frequency effect was argued to reflect the relative strength of the neural lexical representations that are associated with the frequent use of lexical items. However, frequency effects were not observed in some studies, including Bakker et al. (2013) who investigated, along with other factors, the impact of frequency on the processing of past-tense verb forms. The lack of frequency effect was interpreted as supporting the combinatorial account of processing of regular tense verb forms.

The idea of immediate access to lexical information, as indexed by the mismatch response, gave rise to the line of research that explored semantic processing (Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007). In these studies, deviants with different semantic meaning were shown to elicit mismatch negativities with distinct topographies. For example, while the generators of the MMN enhancement to the Finnish word *lakko* 'strike' were localized in bilateral parieto-occipital areas with left-hemisphere dominance, right-hemisphere generators were active for the Finnish word *lakki* 'cap' (Pulvermüller et al., 2004). Topographical discrepancies were also found for movement-related English verbs *pick* and *kick*, as well as for the Finnish face-related *hotki* 'eat' and hand-related *potki* 'pick' (Pulvermüller, Shtyrov, & Ilmoniemi, 2005). The rapidness of the semantic access, reflected by the MMN, was confirmed in a MEG study by Menning et al. (2005), in which semantic congruency was manipulated along with syntactic and phonemic contrasts. The mismatch response to semantic violation was examined in sentences of type *Die Frau düngt den Rasen im Mai.* 'The woman fertilizes the lawn in May' as standard stimuli and *Die Frau düngt den Riesen im Mai.* 'The woman fertilizes the giant in May' as a deviant stimulus. Mismatch fields were elicited between 130–200 ms after critical word onset. The pre-attentive response to semantic violation in sentential context reflected an early access to semantic information. These results were also interpreted as an evidence of rapid semantic integration processes (Pulvermüller & Shtyrov, 2006).

Therefore, together with auditory change detection, mismatch negativity was shown to index language-related processes of higher order. These included the access to lexical information, as reflected by stimulus 'wordness' and frequency-associated distributional patterns, as well as access to semantic meaning in isolated words and sentential contexts.

MMN to morphosyntactic contrasts

The modulations of the mismatch response were also observed in relation to morphosyntactic processing. Specifically, the oddball paradigm was used to explore the effect of grammaticality in simple structures (Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007). The grammaticality effects have been widely investigated using subject-verb agreement violations in English (Puvermüller & Shtyrov, 2003), German (Hasting & Kotz, 2008; Hasting, Kotz, & Friederici, 2007; Jakuszeit, Kotz, & Hasting, 2013; Menning et al., 2005), Finnish (Shtyrov, Puvermüller, Näätänen, & Ilmoniemi, 2003), and French (Brunelliere, Franck, Ludwig, & Frauenfelder, 2007; Brunelliere & Frauenfelder, 2010; Hanna et al., 2013). The generalizability of the effect was tested in a number of studies that examined case-agreement (Pulvermüller & Assadollahi, 2007), word-category (Hasting et al., 2007; Herrmann, Maess, Hasting, & Friederici, 2009) and verb-morphology violations (Bakker et al., 2013). In most of these studies, syntactically incongruent sequences elicited an enhanced syntactic mismatch negativity (sMMN) within 200 ms after the onset of the critical word. This effect was evident, for example, in the study by Hasting et al. (2007), who presented German participants with subject-verb sequences *er faltet* / **er faltest*, *du faltest*/**du faltet* 'he folds / *he fold, you fold / *you folds' in one experiment, and determiner-verb/noun sequences *ein Falter* / **ein faltet*, *er faltet*

/ **er Falter* ‘a butterfly / *a folds, he folds / *he butterfly’ in the second experiment. The enhancement of the MMN mean amplitude was found between 120–180 ms over anterior left regions for subject-verb agreement violations, and between 140–220 ms over anterior and posterior areas for word category violations. These results indicate that both types of violations are detected at very early stages of structure parsing but might be processed in separate brain regions.

Indeed, syntactic MMN shares topographic and temporal features with ELAN, a syntax-related ERP component that peaks at approximately 100–200 ms after the onset of the critical word (Friederici, 2002). Moreover, sMMN and ELAN were shown to have similar neural sources in superior temporal cortex (Friederici, Wang, Herrmann, Maess, & Oertel, 2000; Shtyrov et al., 2003). However, sMMN can be elicited in passive paradigms without linguistic task. Corroborating results were obtained by Pulvermüller, Shtyrov, Hasting, and Carlyon (2008). Their participants did not only passively listen to the stimuli, but were presented with an active auditory distraction task. Independently of the attention load, non-grammatical deviants elicited an early syntactic mismatch response. These findings suggest an early, automatic and pre-attentive processing of syntactic violations.

The grammaticality effect in MMN has been prevailingly explained by syntax-related priming (Bakker et al., 2013; Hasting et al., 2007; Pulvermüller & Assadollahi, 2007; Puvermüller & Shtyrov, 2003). The co-occurrence probability of two morphemes is argued to be mediated by so-called *sequence detectors* that reflect a dynamic link between two morphemes, such as the pronoun *she* and the verbal inflection *–s* (Puvermüller, 2002). In this case, the pronoun and the verbal inflection prime each other. Since priming reduces the amplitude of the ERP components, the non-grammatical constituent, for example zero verbal inflection, elicits a greater negativity than the grammatical morpheme. While the processing of syntactically congruent structures is facilitated by priming, unexpected unprimed morphemes cause an *error signal* that is associated with mismatch response (Shtyrov et al., 2003). The question arises as to whether the sMMN reflects discrete combinatorial processing or probabilistic mapping of syntactic structure. To date, studies explicitly manipulating the factor of co-occurrence frequency of syntactic items in a sequence have shown that the sMMN effects are more likely to be driven by syntactic but not probabilistic processes (Herrmann et al., 2009; Pulvermüller & Assadollahi, 2007).

To summarize, MMN has been shown to be sensitive to morphosyntactic manipulations within 200 ms after the presentation of critical information. This indicates that the processing of syntactic structure is conducted in a rapid automatic manner and does not always require attention. The MMN grammaticality and lexicality effects show distinct patterns: whereas lexicality of the stimulus increases the MMN response, grammatical congruency elicits an MMN of smaller amplitude.

Maturation of the mismatch response

Mismatch negativity was shown to be a developmentally stable component in comparison to other late evoked potentials. However, as many exogenous components, the mismatch response displays developmental tendencies, including the change of the ERP latency, amplitude and scalp distribution (Cheour, 2007; Cheour, Leppänen, & Kraus, 2000).

In several studies investigating phonological contrasts in new-borns and infants up to 12 months, the mismatch negativity response was either substituted or complemented by positivity (Dehaene-Lambertz, 2000; Dehaene-Lambertz & Dehaene, 1994; Friederici, Friedrich, & Weber, 2002; Friedrich, Weber, & Friederici, 2004; Ortiz-Mantilla, Hämäläinen, & Benasich, 2012). Moreover, a positive deflection between 100–300 ms was found in preschool children. Shafer, Yu, and Datta (2010), who investigated the maturation of mismatch response in 4- to 7-year-old children to the English vowel contrast /i – ɛ/, showed a positive mismatch response (pMMR) in children up to the age of 5;5 years. Positive MMR was argued to be an immature response that, however, is unlikely to simply flip polarity with age. Rather, the more mature mismatch negativity was suggested to gradually overlap and mask pMMR that might be present in children from infancy. Functionally, pMMR was assumed to reflect recovery from refractoriness of P100/P1 response. The frontal pMMR was reported in older children in the study by Maurer et al. (2003). In their investigation of the mismatch response to tones and syllables in 6- to 7-year-old children and adults, pMMR with reconstructed left-lateralized sources was elicited in the younger group. According to the authors, these results were due to paradigmatic reasons, including a short stimulus onset asymmetry (SOA) and small acoustic differences between standards and deviants.

The biological origins of the positive mismatch response remain unclear. At least five candidate factors have been suggested to have impact on the response polarity (He, Hotson, & Trainor, 2007; Leppännen et al., 2004):

- methodological differences between experimental designs and analysis procedures, including interstimulus interval duration (Maurer et al., 2003), the choice of reference electrode, and the choice of filter settings (Weber, Hahne, Friedrich, & Friederici, 2004);
- differences in the alertness state of participants (Friederici, Friedrich, et al., 2002);
- maturational differences in the structure of cortical layers underlying positive and negative responses (Trainor et al., 2003);
- functional differences with positivity reflecting perceptual stimulus categorization (Friedrich et al., 2004), or P3a-like involuntary attention switch (Kushnerenko, Čeponienė, Balan, Fellman, & Näätänen, 2002), but not a true mismatch process;
- developmental differences in P1 refractoriness that is masked by mismatch negativity and N1b in children, but not in adults (Shafer et al., 2010).

Despite of the disagreement on the nature of the positive mismatch response there is a clear tendency in literature showing positivity reduction during development by the age of 7 years. The amplitude and the latency of the negative response, on the other hand, undergo some changes during the childhood. Specifically, the mismatch response to non-speech contrasts was reported to show a negative correlation between peak latency and age (Korpilahti & Lang, 1994; Morr, Shafer, Kreuzer, & Kurtzberg, 2002; Shafer, Morr, Kreuzer, & Kurtzberg, 2000). For example, Morr et al. (2002) exposed 3- to 44-month-old infants to the tones with alternating frequencies (1000 Hz versus 2000 Hz) and found that the

MMN peak latency shifted with the rate of 1 ms/month. Linguistic contrasts either elicited an earlier mismatch response in older participants (Paquette et al., 2013; Shafer et al., 2010) or showed no age-related latency differences (Kraus et al., 1993; Kraus, McGee, Sharma, Carrell, & Nicol, 1992). Correlation analyses in the aforementioned study by Shafer et al. (2010) showed that MMN peaks earlier with increasing age. The latency of the MMN peak at the electrode site C4 shifted with the rate of approximately 25 ms/year. Latency-related alternations of the mismatch negativity are consistent with the maturation patterns of other ERP components that might be associated with myelination processes and the acceleration of neural transmissions in developing brain.

The results for the amplitude change remain slightly controversial. On the one hand, it has been claimed that the amplitude of the mismatch negativity tends to follow the inverted U-shape pattern (Cheour et al., 2000). Studies with infants revealed that the MMN amplitude in 3-month-old children was either greater (Cheour et al., 1997) or equal to that in new-borns (Cheour, Alho, et al., 1998). The amplitude of the MMN to phoneme deviant was also enhanced in 12-month old children, as compared to 6-month-old children (Cheour, Čeponienė, et al., 1998). The absence of significant amplitude changes was reported by Morr et al. (2002) for tones in 3- to 44-month-olds and by Glass, Sachse, and von Suchodoletz (2008b) for tones in 2- to 6-year-olds with the ISI of 500 ms. The amplitude of MMN decreased with age in the study of tone discrimination in 4- to 7-year-old children and adults by Shafer et al. (2000). This tendency, however, did not reach statistical significance. Kraus et al. (1993) presented 7- to 11-year-old children and adults with consonant contrasts. In this study, the amplitude of the mismatch negativity decreased with age. Taken together, these results indicate that the amplitude of mismatch response reaches its maximum during the school age. However, this pattern was not confirmed by at least two recent studies: significant amplitude reduction was reported for 3- to 7-year-olds and 8- to 13-year-olds, as compared to adults, in the study by Paquette et al. (2013). Bishop, Hardiman, and Barry (2011) found similar trends for children's, teenagers' and adults' MMN responses to tones and syllable contrasts. Instead of the comparison of mean peak amplitudes, the authors of the latter study used the mean amplitude values in a specific time window, to account for the variance of the ERP response

62in different age groups. It should be noted that tone and speech stimuli were presented to the participants in both studies. The age effects for the MMN amplitude were found for two conditions taken together, that is, no interactions between age and stimulus type were observed.

Age-related MMN changes were also reported in terms of MMN scalp topography. Jing and Benasich (2006) conducted a study on tone discrimination within the first two years of life. They showed that the MMN effect gradually shifted from parietal to frontal areas during this period. Distributional changes of the MMN across age were explained in several ways. On the one hand, the change of orientation and location of the single dipole source in superior temporal gyrus might explain the alternation of distributional pattern. On the other hand, if both temporal and frontal sources contribute to the MMN, the changing activity of the frontal sources over time could be related to the distributional alternation. In line with these findings, the frontal MMN focus was observed to be larger than lateral-temporal focus in adults, whereas 4- to 11-year-old children showed the opposite pattern in the analysis by B. A. Martin, Shafer, Morr, Kreuzer, and Kurtzberg (2003). These results supported the maturational changes over temporal regions observed earlier by Gomot, Giard, Roux, Barthelemy, and Bruneau (2000) in adults, 5- to 7- and 8- to 10-year-old children. Variation in MMN generators and their orientation were argued to be the main factors underlying these changes.

Late ERP components in MMN designs

Along with the mismatch negativity, deviant stimuli elicit a number of later responses in oddball paradigms, mainly a positivity peaking at approximately 250 ms and a late negativity after 280 ms. Depending on the experimental manipulation, the late negative deflection has been discussed as a late MMN (Korpilahti et al., 2001), late discriminative negativity (LDN; Cheour, Korpilahti, Martynova, & Lang, 2001), late syntactic MMN (Hasting et al., 2007), and reorientation negativity (RON; Schröger & Wolff, 1998). In the following, these responses and their function are introduced.

Late positivity. In oddball paradigms, the mismatch negativity often appears together with a positive deflection peaking at approximately 250 ms in fronto-central scalp areas (Picton, 1992; Squires, Squires, & Hillyard, 1975). This positive wave is called P3a and is thought to reflect involuntary attention switching (Escera, Alho, Schröger, & Winkler, 2000) or novelty evaluation (Friedman, Cycowicz, & Gaeta, 2001). According to Escera et al. (2000), P3a should be distinguished from P3b (P300), the component that has more parietal distribution. While P3b is elicited in task-related conditions, P3a is not affected by attention load (Friedman et al., 2001). The amplitude of the positivity depends on the novelty of the deviant item. That is, highly different items elicit a P3a of greater amplitude than slightly different items (Alho et al., 1998). P3a has multiple neural sources including those in the auditory cortex in the superior part of the temporal lobe next to the MMN sources (Alho et al., 1998), and those in prefrontal cortex (Escera et al., 2000).

Late negativity. In a number of studies that used the oddball design, the mismatch negativity was also followed by a later fronto-central negative deflection peaking between 400–600 ms after the point of deviation (Figure 3.1.3, panel A). The second negative wave has been obtained mainly in children (Čeponienė, Cheour, & Näätänen, 1998; Dehaene-Lambertz & Dehaene, 1994; Korpilahti et al., 2001; Kushnerenko et al., 2002; Schulte-Körne, Deimel, Bartling, & Remschmidt, 1998), but also in adults (Alho, Woods, Algazi, & Näätänen, 1992; Schulte-Körne, Deimel, Bartling, & Remschmidt, 2001; Trejo, Ryanjones, & Kramer, 1995). Similar as the MMN, the late discriminative negativity was elicited by vowel change in new-borns, both in active and quite sleep (Martynova, Kirjavainen, & Cheour, 2003). The late negative response to speech and non-speech contrasts has been shown to decrease as a function of age (Bishop et al., 2011; Kraus et al., 1993) and attenuate in clinical populations, such as dyslexic children and adults (Schulte-Körne et al., 1998; Schulte-Körne, Deimel, Bartling, & Remschmidt, 1999; Schulte-Körne et al., 2001), and distractible children (Gumenyuk et al., 2005; Kilpeläinen, Partanen, & Karhu, 1999).

Late negativities, as in Figure 3.1.3, panel B, were observed in response to ungrammatical items between 280–600 ms in syntactic mismatch experiments with adults (Hanna et al., 2013; Hasting et al., 2007; Herrmann et al., 2009; Puvermüller & Shtyrov, 2003). Herrmann et al. (2009) reconstructed the sources of the observed negativity in the left anterior part of the superior temporal gyrus.

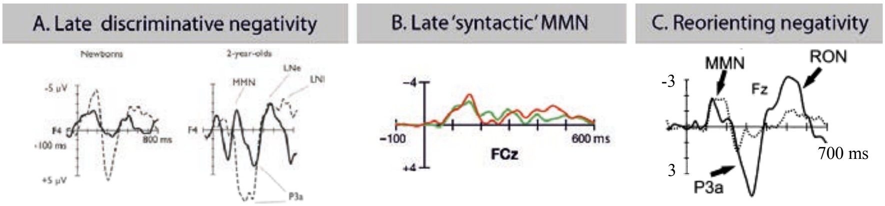

Figure 3.1.3. Late negativities obtained in children and adults in MMN paradigm. A. Difference waves in new-borns (left) and 2-year-olds (right) for the novel (dashed line) and frequency deviant (solid line) conditions. MMN, mismatch negativity; LNe, early phase of late negativity; LNl, late phase of the late negativity. Adapted from Kushnerenko et al. (2002). B. Difference waves for '–t' sequence in Experiment 1 (agreement violation) in correct (in green) and incorrect (in red) conditions. Late negativity between 300–500 ms. Adapted from Hasting et al. (2007). C. Difference waves for ignore (dotted line) and distraction (solid line) conditions. Adapted from Schröger, Giard, and Wolff (2000).

Furthermore, experimental designs that assessed the factor of attention load in MMN, reported a late negative response to task-irrelevant sound changes in adults (Berti & Schröger, 2001; Schröger & Wolff, 1998; Sussman, Winkler, & Schröger, 2003), kindergarten (Wetzel, Berti, Widmann, & Schröger, 2004), and school children (Gumenyuk, Korzyukov, Alho, Escera, & Näätänen, 2004). This response was termed 'reorietation negativity' (RON; Figure 3.1.3, Panel C). In children, the RON response was topographically more wide-spread in comparison to adults, in which the effect was focused in frontal areas (Wetzel et al., 2004). Schröger et al. (2000) suggested that RON generators are located in frontal brain areas.

In view of the various paradigms, age groups, and stimulus types mentioned so far, the functional role of the late negativity remains a matter of debate. On the one hand, in the study by Korpilahti et al. (2001), a greater late negativity was elicited by more complex stimuli, that is, by words and pseudowords, but not by tones. Consequently, the authors suggested that the late negativity peaking between 400–450 ms reflected the processing of lexical differences between items. However, studies by Čeponienė et al. (1998), Alho et al. (1992), and

Kushnerenko et al. (2002) have shown that a similar late negativity can be elicited by the auditory change in tonal material. Čeponienė et al. (1998) argued that due to its latency, the late response can hardly originate from the sensory level. Rather, it might have the MMN-like function, that is, reflect further pre-attentive cognitive-level processing of the acoustic change (Čeponienė et al., 2004). Barry, Hardiman, and Bishop (2009) suggested that the late negativity indexes the establishment of phonological representation that might involve additional cortical structures (Hill, McArthur, & Bishop, 2004). Another model explained the late response as reflecting the transfer of the learned pattern to the long-term memory (Zachau et al., 2005). In this view, there is a negative relationship between the amplitude of the late negativity and the familiarity of the pattern, which explains the predominant presence of the component in young populations. Escera et al. (2000) discussed the late negativity as an attention-related component. Based on the findings by Schröger and Wolff (1998), the late negativity was interpreted as reflecting attention reorienting towards task-relevant information that follow distraction. Thus, in contrast to P3a, the functional role of the late negativity in mismatch paradigms remains unclear.

Unlike mismatch negativity, the late negativity is argued to lack stability across age groups (Cheour et al., 2001). In the aforementioned experiment by Kraus et al. (1993), the contrasts /ga – da/ and /ga – ba/ elicited a late negativity starting at 400 ms. No latency differences were found between adults and children in this study, but the late negativity was shown to have a significantly larger amplitude and to be more robust in children than in adults. Similar results were obtained by Bishop et al. (2011), who reported larger mean amplitude and later peak latencies of the late negativity to syllable contrasts for younger groups than for older groups. Thus, linguistic experience appears to modulate the amplitude and the latency of the late mismatch response.

Current study

In the current study we tested the ability to differentiate between *der* and *den* in children and adults. Three variants of oddball paradigms were used. These paradigms differed in several ways. Specifically, the duration of the experimental measurement was adjusted to the age of the participants (Experiment 1a). Experiment 1a with 2-year-olds consisted of one block that took only nine minutes of EEG recording. While the overall duration of the measurement allowed for high retention rates in our youngest group, it was hardly feasible to make comparisons between standard and deviant conditions for each determiner separately in this between-subject design. All such comparisons might be confounded by individual differences between our participants.

In Experiment 1b with 2-year-olds, we attempted to overcome these drawbacks by adding a block with reversed stimulation, such that determiners were presented both as standards and deviants within one session. Using this design, we were able to calculate mismatch difference waves for each determiner separately (Näätänen et al., 2007; Pulvermüller & Shtyrov, 2006). This doubled the length of the EEG measurement to almost 20 minutes, and as a result decreased the retention rates considerably (see section *Data analysis*). Note, that the two-block design might also have impact on the global refractoriness of the MMN response, leading to the pattern asymmetry. The concept of alternating blocks in within-subject design was further developed in the Experiment 1c with 3-year-olds. In this experiment, children were exposed to the auditory stimulus in four blocks, in which the determiners *der* and *den* were presented in alternation. As a control group, adults were also presented with the paradigm used in Experiment 1c.

3.2 Experiment 1a: 2-year-old children at group level

In Experiment 1a, we tested whether 2-year-olds are able to differentiate between the articles *der* and *den*, as reflected by a mismatch response. Between-subject design was chosen to reduce the overall length of the experiment. Based on the previous literature on mismatch response to phonological contrasts in young children, we hypothesized that

- the mismatch negativity will be elicited in fronto-central areas between 150–400 ms after the point of acoustical deviation (Niemitalo-Haapola et al., 2013; Paquette et al., 2013);

- late negativity will be elicited in fronto-central areas between 300–600 ms after the point of deviation (Bishop et al., 2011; Korpilahti et al., 2001);
- in individual participants, the mismatch response will be either absent or substituted by a positive mismatch response (Shafer et al., 2010).

Methods

Participants

Sixty-six two-year-old children took part in Experiment 1a (age range 24–35 months, M_{age} = 29.89 months, *SD* = 3.28 months, 39 girls). Informed parental consent was obtained for all children before the experiments. EEG recording was not possible in five children. Furthermore, 12 children were excluded due to various reasons: bilingual environment (one child), neurological and/or hearing disease history (three children), and lack of qualitative data (eight children, see *Data Analysis* for details). The final data analysis for Experiment 1a thus included the datasets of 49 children (age range 25–35 months, M_{age} = 29.95 months, *SD* = 3.17 months, 29 girls).

Participating families were recruited for the longitudinal study conducted by in the Neuropsychology department of Max-Planck-Institute for Human and Brain Sciences, Leipzig. Fixed travel costs were paid to the parents. Children received a present of their choice after completing the EEG experiment and psychometric tests.

Materials

Der and *den* are the morphological forms of the German definite article. The paradigm of the definite article in Table 3.2.1 shows that there is no one-to-one relation between the grammatical meaning and the form of the article, that is, *der* can mark nominative masculine singular, dative feminine singular as well as genitive plural nouns. Similar overlap is observed for the form *den* that can mark both accusative masculine singular and dative plural forms. *Der* and *den* unambiguously indicate syntactic/thematic functions only in singular masculine nouns (Haider, 2010).

Table 3.2.1: The morphological paradigm of the German definite article.

	Singular			**Plural**
	masc.	***neut.***	***fem.***	
Nominative	**der**	das	die	Die
Accusative	**den**	das	die	Die
Dative	dem	dem	**der**	**Den**
Genitive	des	des	der	**Der**

A usage-based analysis of the articles *der* and *den* has revealed that, independently of the grammatical meaning, *der* occurs in speech more frequently than *den*. This could be shown both for the written and spoken modalities in a number of German corpora (Table 3.2.2). In fact, the relative occurrence frequency of the form *der* in spoken and written German was at least twice higher than the relative frequency of the form *den*. Furthermore, the analysis of CHILDES data (MacWhinney, 2000) has shown that *den* is used less than *der* by both 2- and 3 year-olds, but the occurrence of *den* in spontaneous speech increases with age.

Table 3.2.2: Absolute and relative occurrence frequencies of the articles *der* and *den* in German corpora. Relative frequencies are normalized as per one million of tokens.

Corpus	**Modality**	**Corpus size (in tokens)**	**Absolute frequency**		**Relative frequency**	
			der	***den***	***der***	***den***
Deutsches Textarchiv	written	98964704	1436642	768636	14516.71	7767.77
Kernkorpus 20	written	103432000	1909160	967205	18458.12	9351.12
Kernkorpus 21	written	1547000	23234	14697	15018.75	9500.32
Deutsches Referenzkorpus (DeReKo)[6]	written	4278210573	142612969	47185166	333347.24	11029.18
Gesprochene Sprache	spoken	2500000	38317	17802	15326.8	7120.8
Datenbank für Gesprochenes Deutsch (DGD)[7]	spoken	7411613	127189	52519	17160.77	7086.04
CHILDES 2yo	spoken	635486	13471	4004	21197.95	6300.69
CHILDES 3yo	spoken	298955	6510	2579	21775.85	8626.72

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[6] Only data from the subcorpus *Archiv der geschriebenen Sprache* was analyzed.

[7] Data from the subcorpus *Emigrantendeutsch in Israel* was excluded the analysis.

For the auditory discrimination experiment, the articles *der* and *den* were recorded by a trained female speaker in a sound-isolated booth. They were matched for the intensity in MATLAB (The MathWorks, Inc., Natick, MA, USA). The acoustic analyses of the stimuli and pitch manipulations were conducted using Praat (Boersma & Weenink, 2014). In the following, the main parameters of the stimulus material are presented.

Duration. The stimulus items had the duration of 400 ms. In both words, the formant transition from the plosive [d] to the following vowel occurred at around 27 ms, as evidenced by the formant shift at this point (Figure 3.2.1). Based on the behaviour of the formants F1, F2 and F3 in *den*, the transition point between the vowel [ɛ] and the nasal consonant [n] was defined at 182 ms. Thus, the duration parameters of the first consonant, vowel and the second consonant in *den* were 27 ms, 155 ms, and 245 ms, respectively.

The combination of the vocal [ɛ] and the uvular approximant [ʁ] at the end of *der* was realized as a phonetic diphthong [ɛɐ̯] (cf. Kohler, 1995, p. 166). The vocalization of the approximant could be observed starting at around 158 ms. At this point, the jaw-like opening constituted by the formants F2 and F3, was combined with the slow growth of F1 and perturbations in F4. Thus, the vowel part of the diphthong [ɛ] was stable during 131 ms in *den*. It was followed by the approximant [ʁ] during the next 212 ms. In total, the diphthong had the length of 343 ms.

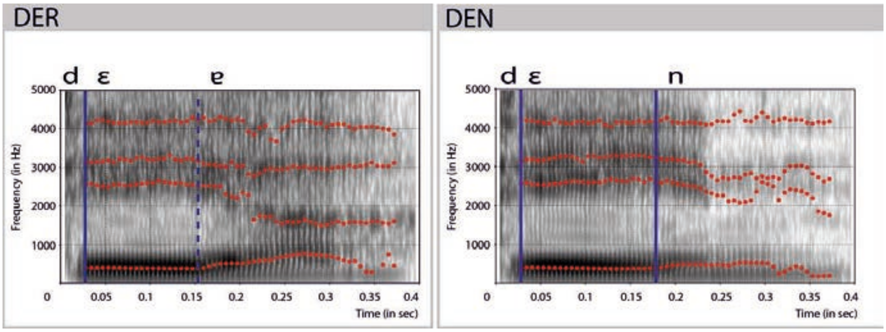

Figure 3.2.1: Spectral characteristics of the stimulus items *den* and *der*. Formants F1, F2, F3, F4 are shown in red dotted lines. Blue vertical lines indicate transition points between the consonants and vowels. Dashed vertical blue line indicates the approximate transition point between two parts of the diphthong.

Acoustic analysis shows that the articles diverge in spectral characteristics at 158 ms after the onset of the word. In *der*, gliding to the approximant starts at this latency. The vowel offset lies approximately 30 ms behind this point in *den,* and might be affected by the nasalization that stems from the preparation of the articulatory apparatus for the nasal consonant. Taking in consideration these results, the point of physical deviance (i.e., the point at which the differences can be processed) was defined at 158 ms.

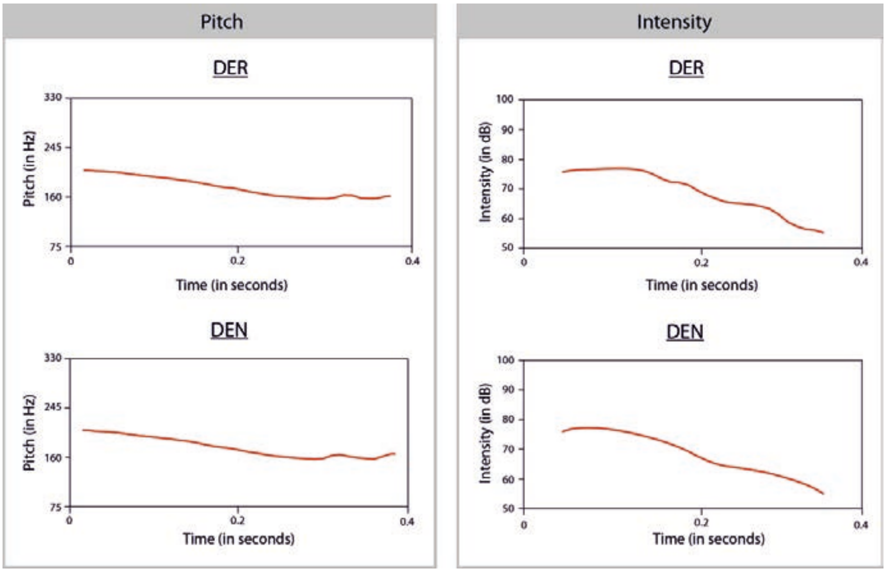

Figure 3.2.2. Pitch (left panel) and intensity (right panel) contours of the determiners *der* and *den*.

Frequency. The values of the formants F0, F1, F2, F3 and F4 were collected from the onset of the vowel at 27 ms to the formant offset at 371 ms to define the main frequency characteristics of the stimulus items. Similar measurements were performed for the vowel (27–158 ms) and transition area including the vowel and the following nasal/approximant (158–371). As can be seen in Table 3.2.3, stimuli were well matched for the fundamental frequency F0. The pitch contour was slowly falling towards the end of the word (Figure 3.2.2, left panel).

The frequencies of the formants F1 and F2 reflected the articulatory-acoustic relationships in terms of height and backness (Kent & Read, 1992). High diphthong [ɛɐ̯] in *der* had a higher frequency of the first formant than the low transition [ɛn] in *den*. On the other hand, the position of the tongue for the [ɛɐ̯] was closer to the back of the mouth than that for the [ɛn], which was reflected by the lower F2 value in *der* (Table 3.2.3).

Table 3.2.3. Formant and intensity characteristics of the stimuli *der* and *den*.

		F0	**F1**	**F2**	**F3**	**F4**	**Intensity**
Mean 27–371 ms	*der*	176	529	2116	3093	4128	73
	den	177	406	2452	3044	4174	73
Vowel 27–158 ms	*der*	196	390	2566	3197	4191	76
	den	196	388	2602	3235	4146	76
Transition 158–371	*der*	165	614	1838	3030	4088	68
	den	165	417	2359	2926	4190	66

Note. Mean formant (in Hz) and intensity (in dB) values were measured from the offset of the first consonant (27 ms) to the formant offset at 371 ms. Vowel formant (in Hz) and intensity (in dB) values were measured from the offset of the first consonant to the point of deviation at 158 ms. Transition formant (in Hz) and intensity values (in Hz) were measured from the point of deviation to the formant offset.

Intensity. Experimental items were matched in terms of intensity using root mean square (RMS) amplitude in order to approximate perceived loudness of the stimulus material (Figure 3.2.2, right panel).

Experiment Ia consisted of one block, in which either *der* or *den* was presented as a standard (Figure 3.2.3). Half of the children received *den* as a standard, whereas another half received *der* as a standard. The stimulus items were presented with a fixed interstimulus interval (ISI) of 500 ms from offset to onset of the next item in a pseudorandomized order. The duration of the EEG measurement was approximately 9 minutes. This design allowed for between-subject comparison of the auditory discrimination between two items realized in a relatively short experiment.

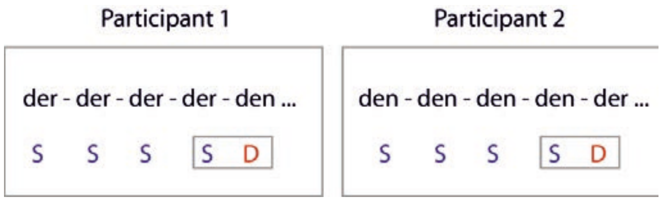

Figure 3.2.3. Design of the Experiment 1a. Standards are marked with S, deviants are marked with D. The S-D pair illustrates the items that were included the analysis of difference wave.

Procedure

All the EEG recordings were preceded by a warm-up session, during which the experimenter explained the procedure to the caregivers and played with the child. The sensor cap and the recording booth were introduced to the child. Medical-technical assistant applied the electrode cap while the child was seating on her parent's lap outside the cabin. During the set-up and impedance measurements, the child was comforted by toys and books. Parents were solicited for assistance if necessary. Most of them were actively engaged in distracting the child, in preventing her to remove the electrode cap and praising for cooperation.

For EEG recordings, participants were seated on their parents' lap in an electrically-shielded cabin in front of the video graphics array (VGA) Sony monitor (Sony, Tokyo, Japan) based on cathode ray tube (CRT) technology. The front of the monitor was covered by a black-coloured paper frame leaving a 29x22-cm window. The distance between the participant and the monitor was approximately 110 cm. During the presentation of the stimuli in Experiment Ia, a silent cartoon film "The mole and the little hare" (Miler, 1997) was shown. Stimuli were presented aurally using Presentation (Neurobehavioral Systems, Inc, Albany, CA, USA) with the average intensity of 50 dB via Bowers & Wilkins loudspeakers (B&W Group Germany GmbH, Halle, Germany). Loudspeakers were located at approximately 140 cm in front of the participants. Small noiseless toys were allowed in the cabin unless they caused excessive excitement. Parents wore ear plugs and were instructed to remain quite during the whole experiment. Participants' behaviour was monitored via camera and microphones that were installed in the cabin.

EEG recording

EEG data was recorded at 129 electrode sites using Geodesic Sensor Nets (Electrical Geodesics, Inc., Eugene, OR, USA) with the operating impedance of 50 kΩ. The data was digitized online at a rate of 500 Hz and referenced to Cz electrode. The electrode COM, placed next to the vertex, served as a common ground.

Data analysis

Electrophysiological data was processed using software tools EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) in the MATLAB environment (The MathWorks, Inc., Natick, MA, USA). The data was offline down-sampled to 250 Hz, band-pass filtered between 0.3 and 20 Hz (Kaiser windowed sine FIR filter), and rereferenced to linked mastoids (electrode sites E57 and E100). The algorithms exploiting the infomax Independent Component Analysis (ICA) were used to correct stereotyped artefacts such as eye movements, eye blinks and muscle activity (Bell & Sejnowski, 1995; Jung, Makeig, Bell, & Sejnowski, 1998; Jung et al., 2000; see also Appendix D for details of preprocessing).

Epochs time-locked to the stimulus onset were extracted. The length of the epoch was 1000 ms, including a 100-ms pre-stimulus baseline. Remaining artefact-contaminated epochs were automatically rejected if the amplitude exceeded the absolute threshold of 150 μV and/or of seven standard deviations of the mean probability distribution. The first 10 epochs were excluded from the analysis. Only standard items immediately preceding the deviants were included into the individual ERPs, that is, the number of trials in standards and deviants was kept equal for all ERP comparisons. Eight individual averages (13% of all datasets) were removed from the grand average because they contained EEG responses to less than 75% of presented trials. Difference waves were constructed by subtracting the response to the standard stimuli *den/der* from the response to the deviant stimuli *der/den*.

Nine regions of interest (ROIs) were defined in anterior-posterior and lateral planes: anterior-left (AL), anterior-middle (AM), anterior-right (AR), central-left (CL), central-middle (CM), central-right (CR), posterior-left (PL), posterior-middle (PM), posterior-right (PR) (Figure 3.2.4). Electrodes located at the utmost rows of the cap were excluded from the analysis. Table 3.2.4 lists the electrodes included into specific ROIs.

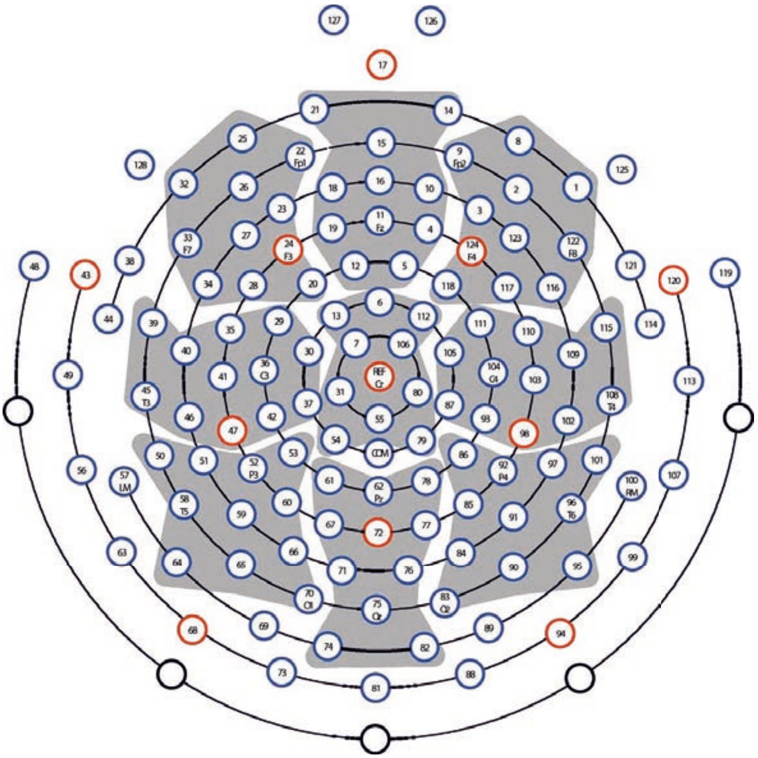

Figure 3.2.4. 128-channel map showing nine regions of interest. AL, anterior-left; AM, anterior-middle; AR, anterior-right; CL, central-left; CM, central-middle; CR, central-right; PL, posterior-left; PM, posterior-middle; PR, posterior-right.

Table 3.2.4. Regions of interest defined for statistical analyses.

ROI	Electrodes
Anterior-left (AL)	32, 25, 26, 22 (Fp1), 23, 27, 33 (F7), 34, 28, 24 (F3), 20
Anterior-middle (AM)	21, 18, 15, 16, 11 (Fz), 12, 5, 4, 10, 14, 19
Anterior-right (AR)	9 (Fp2), 8, 3, 2, 1, 122 (F8), 123, 124 (F4), 116, 117, 118
Central-left (CL)	39, 40, 41, 42, 45 (T3), 46, 47, 35, 36 (C3), 37, 29, 30
Central-middle (CM)	13, 7, 129 (Cz), 31, 55, 54, 79, 80, 106, 112, 6
Central-right (CR)	108 (T4), 109, 110, 111, 102, 103, 104 (C4), 105, 115, 87, 93, 98
Posterior-left (PL)	50, 51, 52 (P3), 53, 58 (T5), 59, 60, 64, 65, 66, 70 (O1)
Posterior-middle (PM)	61, 62 (Pz), 78, 67, 72, 77, 71, 76, 75 (Oz), 74, 82
Posterior-right (PR)	83 (O2), 84, 85, 86, 90, 91, 92 (P4), 95, 96 (T6), 101, 97

Note. Labels of the standard 10-20 system are indicated in parentheses.

Statistical analyses were performed using PASW Statistics 22 (SPSS, Inc). A repeated measures analysis of variance (ANOVA) with factors Stimulus Type

[Standard; Deviant], anterior-posterior plane [Anterior; Central; Posterior], and lateral plane [Left; Middle; Right] was performed. Interactions involving the factor Stimulus Type were further step-down analyzed using one-way/two-way repeated measures ANOVA. Corrections using the Greenhouse-Geisser method were applied if the assumption of sphericity was violated, as indicated by the Mauchly's test of sphericity (Greenhouse & Geisser, 1959). Voltage topographies were computed using mean amplitudes for the windows of interest.

In order to define the time windows (TWs) critical for the mismatch response, the statistical analyses were performed using mean amplitudes in consecutive windows of 50 ms starting with word onset. These TWs were: 0–50 ms, 50–100 ms, 100–150 ms, 150–200 ms, 200–250 ms, 250–300 ms, 300–350 ms, 350–400 ms, 400–450 ms, 450–500 ms, 500–550 ms, 550–600 ms, 600–650 ms, 650–700 ms, 700–750 ms, 750–800 ms, 800–850 ms, and 850–900 ms.

Local mismatch response peaks were defined automatically using ERPLAB Measurement Tool (Lopez-Calderon & Luck, 2014) within the latency range in which statistically significant differences between stimulus types were observed. The peaks were inspected visually to explore the proportion of negative and positive mismatch responses.

Results

Figure 3.2.5 shows event-related potentials for standard and deviant stimulus types at the representative electrode sites for each ROI. A sustained negativity starting at around 250 ms could be observed. The negativity had a moderate peak at approximately 400 ms at central and frontal electrodes that was followed by a slow negativization between 450–900 ms.

Statistical analyses in the consecutive 50-ms windows revealed the main effect of Stimulus Type between 300 and 900 ms (Table 3.2.5). Additionally, an interaction Stimulus Type × AP was found in the time ranges 400–500 ms and 600–900 ms. Separate analyses of the interactions showed that the effect was present in all regions along the anterior-posterior plane except for the window 850–900 ms, where it was absent in posterior areas. Similarly, the analysis of the interaction Type × LP, which was found in the time range 350–900 ms, did not indicate any specific regions of the effect distribution. However, voltage topographies, as represented in a separate box in Figure 3.2.5, have shown an asymmetric pattern with the negativity being more pronounced in the left scalp areas.

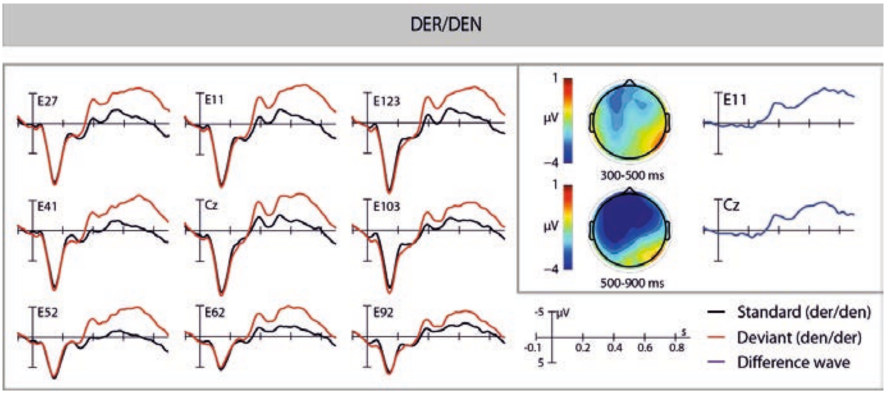

Figure 3.2.5. ERP response to the standard (in black) and deviant (in red) elicited in 2-year-old children in Experiment Ia. For voltage topographies mean amplitudes between given latencies were calculated at deviant-minus-standard difference wave (in blue). Negativity is plotted upwards.

A positive mismatch response between 300–500 ms was found in 10 children, that is, in about 20% of the datasets that were included into grand average. Individual responses are illustrated in Figure 3.2.6.

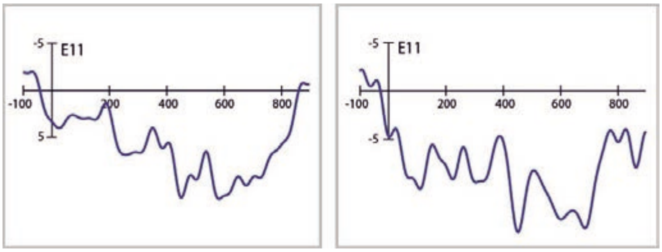

Figure 3.2.6. Examples of a positive mismatch response шт 2year-old children.

The mean amplitude of the MMN local peak, as defined between 300–500 ms at Fz, was -4.96 μV (*SD* = 7.41 μV). The mean latency of the MMN peak at Fz was 401 ms (*SD* = 43 ms). Taken in consideration the point of stimulus-deviance at 158 ms, the MMN peaked at 243 ms after the point of physical deviation. The peak of the late negative response was defined in the TW 500–900 ms. The late negativity peaked at 707 ms (*SD* = 113 ms) with the amplitude of -9.11 µV (*SD* = 5.98 µV), that is, at 549 ms post-deviance.

Table 3.2.5. Analysis of variance as calculated in Experiment Ia in 2-year-old children for comparison standard *der/den* versus deviant *den/der*.

TW	**Main effect of stimulus type *F*(1, 48)**	**Type × AP (df) F**	**Type × AP Resolved**			**Type × LP (df) F**	**Type × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
300–350	5.71*								
350–400	18.60**					(2, 96) 3.27*	23.73**	16.55**	10.85**
400–450	17.91**	(1.26, 60.53) 3.92*	15.83**	14.02**	10.56**	(2, 96) 15.92*	28.24**	14.92**	8.82**
450–500	12.25**	(1.26, 60.60) 4.19*	11.68**	9.99**	6.97*	(2, 96) 4.93**	19.48**	10.90**	6.12*
500–550	18.38**					(1.64, 78.91) 3.75*	27.73**	18.09**	8.02**
550–600	25.22**					(1.62, 77.98) 4.67*	31.91**	26.43**	11.62**
600–650	27.31**	(1.23, 59.05) 3.99*	19.52**	22.14**	26.27**	(1.75, 83.89) 5.74**	35.62**	26.68**	14.05**
650–700	30.83**	(1.20, 57.56) 8.04**	24.78**	26.50**	21.97**	(1.78, 85.28) 7.68**	42.42**	29.41**	16.76**
700–750	34.03**	(1.29, 61.84) 12.75**	30.68**	31.68**	15.17**	(1.75, 83.74) 6.56**	50.28**	29.92**	18.00**
750–800	29.51**	(1.26, 60.35) 12.55**	28.27**	26.89**	8.52**	(1.68, 80.68) 5.80*	41.66**	25.47**	15.22**
800–850	23.94**	(1.27, 60.92) 13.13**	25.50**	21.54**	4.07*	(2, 96) 4.70*	39.43**	19.92**	12.03**
850–900	20.74**	(1.25, 60.18) 9.13**	21.70**	15.97**	-	(2, 96) 5.98*	39.78**	16.44**	7.78**

Note: TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, midline; RIGHT, right. p ≤ 0.01**, 0.01 < p ≤ .05*.

Twenty-two of 49 children received *der* as a standard item and *den* as a deviant item (*der* group). Another 29 children received *den* as a standard item and *der* as a deviant item (*den* group). Table 3.2.6 summarizes the mean amplitudes and latencies for each of the *der* and *den* groups. The differences in amplitudes and latencies of the early mismatch response between groups were not statistically significant, as assessed by independent-samples t-test (for amplitude: $t(47) = .28$, $p = .779$; for latency: $t(43.23) = -1.14$, $p = .259$). Similarly, the type of deviant did not have effect on the latency and amplitude of the late negativity (for amplitude: $t(47) = -.20$, $p = .842$; for latency: $t(47) = 1.86$, $p = .070$).

Table 3.2.6. Mean amplitudes and latencies of the mismatch response and late negativity at the electrode Fz.

	Der group	*Den* group
Number of participants	26	23
Mean age (months)	30.27 (3.44)	29.61 (2.87)
Gender	15 girls	14 girls
MMN: mean amplitude (μV)	-5.24 (7.85)	-4.64 (7.05)
MMN: mean peak latency (ms)	408 (51)	394 (32)
Late negativity: mean amplitude (μV)	-8.95 (6.68)	-9.29 (5.22)
Late negativity: mean peak latency (ms)	680 (105)	738 (115)

Note. ‘Der group’ received der as a standard, den as a deviant. ‘Den group’ received den as a standard, der as a deviant. Mean amplitudes are calculated in relation to the stimulus onset. Standard deviation of the mean is indicated in parentheses.

Discussion

In Experiment 1a, we tested 2-year-old children’s auditory discrimination between two determiners *der* and *den* in between-subject design. In the oddball paradigm, a sustained negative mismatch response between 300–900 ms after stimulus onset was observed. The effect was widely distributed over the scalp and seemed to be larger over the left hemisphere. This tendency, however, did not reach significance.

Although the mismatch negativity response did not have a clearly defined peak, two negative deflections were chosen based on the previous literature and statistical evaluation. An early mismatch negativity peaked at 243 ms after the point of deviation. The peak of the late mismatch negativity was found at 559 ms post-deviance.

The observed pattern was comparable with the response to the phonological contrasts in children. The amplitude of the early mismatch response was within the range (-.5 to -6 μV) reported in previous studies for speech stimuli in preschool children (Čeponienė, Lepistö, Alku, Aro, & Näätänen, 2003; Niemitalo-

Haapola et al., 2013; Paquette et al., 2013). Its peak latency was similar to that obtained in 3-year-old children for the vowel contrast /a – o/ (Čeponienė et al., 2003), to the vowel contrast /i – ɛ/ in 4- to 7-year-olds (Shafer et al., 2010), to the consonant contrasts /ba – da/, /ba – ta/ in 6- to 7-year-olds (Maurer et al., 2003; Paquette et al., 2013), and to the consonant contrasts /ba – ga – da/ in 7- to 10-year-olds (Uwer & von Suchodoletz, 2000). It was approximately 20 ms later in comparison to the response obtained by Niemitalo-Haapola et al. (2013) to the vowel contrasts in /pi – pe – ki – ke/. The latency discrepancy might be explained by the use of a rapid multi-feature paradigm in the study by Niemitalo-Haapola et al. (2013), in which multiple sounds were presented in a short period of time (see also Lovio et al., 2009 for paradigmatic comparisons)

The late negativity peaked at 549 ms post-deviance, that is, somewhat later than reported in previous studies. In the study by Bishop et al. (2011), the late discriminative negativity peaked between 410–470 ms in 7- to 12-year-old children. Six- and seven-year-olds' late response in the experiments by Korpilahti et al. (2001) and Alonso-Bua, Diaz, and Ferraces (2006) fell into the similar range. In 3-year-olds, the peak of the second negativity to the vowel contrast was between 510–530 ms (Čeponienė et al., 2003). Niemitalo-Haapola et al. (2013) did not discussed data on late negativity in 2-year-olds, although their ERP plots showed a late negative deflection with peak at approximately 450 ms (Niemitalo-Haapola et al., 2013, p. 104; Figure 2).

It should be noted that the peak latency obtained in the current study had a greater variance than those observed in the previous reports. We assume that the delay in the peak latency of the second component is related to the phonetic features of the presented material. Commonly, speech stimuli presented in oddball paradigms differ in only one phoneme or acoustic feature, for example, in consonant (/ba/ versus /ga/) or in vowel (/tuli/ versus /tu:li/). In the current experiment, naturally spoken determiners *der* and *den* were used. At the phonemic level, they differed in the final consonant. At the phonetic level, however, they could be further distinguished by the acoustic representation of the vowel. While the phoneme /ɛ/ was realized as a nucleus of the diphthong in *der*, /ɛ/ in *den* was partially nasalized under the influence of the adjacent nasal consonant

/n/. Thus, our stimuli contained more than one distinguishing feature towards the end of the word. Combination of deviance features, for example, tone duration and tone alternation was shown to elicit two negativities in adults (Winkler & Czigler, 1998). Complexity of acoustic differentiation might trigger prolonged processing with considerable variability in children.

Taken together, the results of the Experiment 1a indicate that 2-year-old children are able to automatically discriminate between the articles *der* and *den* at group level.

3.3 Experiment 1b: 2-year-old children

The design of Experiment 1a allowed for the group analysis of children's capacity to differentiate between two determiners. Half of our participants were presented to the standard *der* and another half to the standard *den*. The corresponding deviants *der* and *den* have elicited a negative mismatch response in children. This mismatch response may be confounded by a number of factors. First, since the factor Stimulus Type was tested in a between-subject design, and children exposed to different standards/deviants were not matched in terms of age, gender and other characteristics, individual differences between participants could have impact on the mismatch response. Second, purely acoustic differences between standards and deviants can contribute to the mismatch response. The impact of these factors can be reduced in a within-subject design in which each participant is exposed to both articles in both conditions. Comparisons of stimulus types (deviant versus standard) for each article allow for the assessment of the ability to discriminate between two articles while mitigating the influence of acoustic differences.

In Experiment 1b, we expect to replicate the main findings of the Experiment 1a, that is to find

- a mismatch negativity with a fronto-central scalp topography between 150–400 ms after the point of acoustic deviation (Niemitalo-Haapola et al., 2013; Paquette et al., 2013);

- a late negativity 300–600 ms after the point of deviation (Bishop et al., 2011; Korpilahti et al., 2001).

Methods

Participants

Forty-four 2-year-old children participated in Experiment 1b (age range 14–35 months, M_{age} = 30.19 months, *SD* = 2.85 months, 20 girls). Informed parental consent was obtained for all children before the experiments. The data of one child was excluded from the analysis due to the neurological disease history. EEG recording was not possible in one child. The data for only one block were recorded in four children. The measurements of 26 children did not contained enough data (see *Data Analysis* for details). Thus, the final grand average included the datasets of 15 two-year-old children (age range 15–35 months, M_{age} = 30.20 months, *SD* = 2.86 months, four girls).

Materials

Experiment 1b used the same recorded items as Experiment 1a. Experiment 1b consisted of two blocks, in which standards and deviants were alternating. While *der* functioned as a standard in one block, *den* was established as a standard in another block (Figure 3.3.1). The duration of the Experiment 1b was approximately 18 minutes. A break was included if it was necessary. The stimulus items were presented with a fixed ISI of 500 ms from offset to onset of the next item in a pseudorandomized order. This design allowed for a within-subject comparison of a single item in both standard and deviant conditions at a cost of experiment duration.

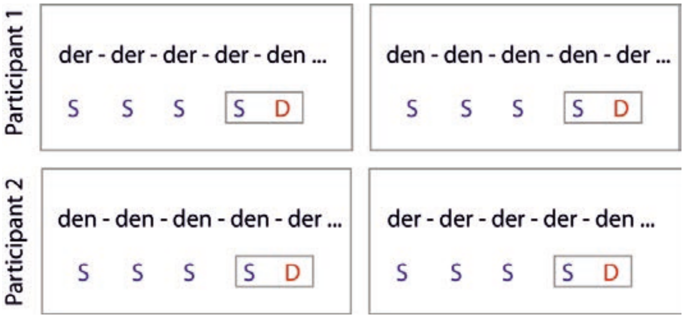

Figure 3.3.1. Design of the Experiment 1b. Standards are marked with S, deviants are marked with D. The S-D pair illustrates the items that were included into analysis of difference wave.

Procedure

Experiment 1b had the same procedure as Experiment 1a. Since Experiment 1b was longer, a short film "The flower" (Kerp, 2001) was presented during the second block.

EEG recording

EEG was recorded with the same parameters as in Experiment 1a.

Data analysis

Data analysis was performed as in Experiment 1a. However, 14 (56%) of 25 available datasets had to be excluded from the grand average due to the lack of qualitative data, that is, at least 75% trials containing artefact-free brain response. In contrast to the Experiment 1a, epochs containing standard *der*, standard *den*, deviant *der*, and deviant *der* were averaged separately to build ERPs. Thus, the confounding acoustic factors of the stimulus comparison could be minimized.

Results

Deviants *der/den* elicited a sustained negativity starting at around 300 ms (Figure 3.3.2).

The main effect of factor Stimulus Type was found for consecutive windows between 300–900 ms (Table 3.3.1)[8]. The interaction between the factor Stimulus Type and distributional factor in anterior-posterior plane was significant between 350–550 ms and 650–900 ms. Analysis of these interactions showed that the strongest mismatch response was spread over anterior and central scalp areas. No lateralization effects were found.

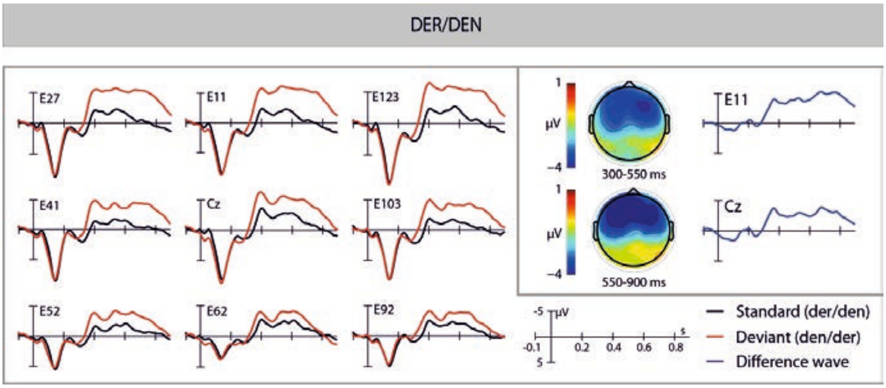

Figure 3.3.2. ERP response to the standard (in black) and deviant (in red) elicited in 2-year-old children in Experiment Ib. For voltage topographies mean amplitudes between given latencies were calculated at deviant-minus-standard difference wave (in blue). Negativity is plotted upwards.

Based on the distributional pattern, two TWs for peak detection were defined: an early TW 300–550 ms, and a late TW 550–900 ms. The mean amplitude of the first peak at Fz was -5.84 µV (*SD* = 3.36 µV). The mean latency of the first peak was 439 ms (*SD* = 69 ms), that is, 281 ms post-deviance. The mean amplitude of the late mismatch response was -7.37 µV (*SD* = 3.62 µV). It was peaking at 709 ms (*SD* = 87 ms), that is, at 551 ms post-deviance.

Separate difference waves were calculated for each determiner in both conditions. Both forms elicited a negative deflection. However, the patterns of these negativities were not identical. In case of *der*, the negativity started at around 300 ms and had two pronounced peaks (Figure 3.3.3, left panel).

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[8] Difference waves in Figure 3.3.2 (separate box) show a very early positivity between 0 and 100 ms. In fact, the effect of Stimulus Type was significant in the first 50 ms ($F(1, 14) = 5.58$, $p = 0.035$). This early difference, however, might be explained by a high signal-to-noise ratio in the EEG recordings of 15 two-year-old children.

Table 3.3.1. Analysis of variance as calculated in Experiment 1b in 2-year-old children for comparison: standard *der/den* versus deviant *den/der*.

TW	Main effect of stimulus type *F*(1, 14)	Type × AP	Type × AP Resolved		
			ANT	CENT	POST
300–350	15.65**				
350–400	34.24**	(1.40, 19.63) 5.65**	38.45**	26.28**	10.11**
400–450	16.32**	(2, 28) 8.98**	23.20**	14.49**	-
450–500	13.25**	(2, 28) 11.02**	22.81**	11.38**	-
500–550	14.59**	(2, 28) 5.12*	20.86**	13.39**	-
550–600	14.70**				
600–650	15.06**				
650–700	15.71**	(1.31, 18.31) 7.69**	19.09**	15.48**	4.63*
700–750	14.80**	(1.41, 19.75) 12.48**	23.01**	17.37**	-
750–800	12.74**	(1.44, 20.12) 15.05**	22.69**	13.92**	-
800–850	7.79*	(1.30, 18.09) 10.29**	14.52**	8.13*	-
850–900		(1.32, 18.41) 7.29**	8.83**	-	-

Note. TW, time window; AP, anterior-posterior plane; ANT, anterior; CENT, central; POST, posterior. $p \leq 0.01$**, $0.01 < p \leq .05$*.

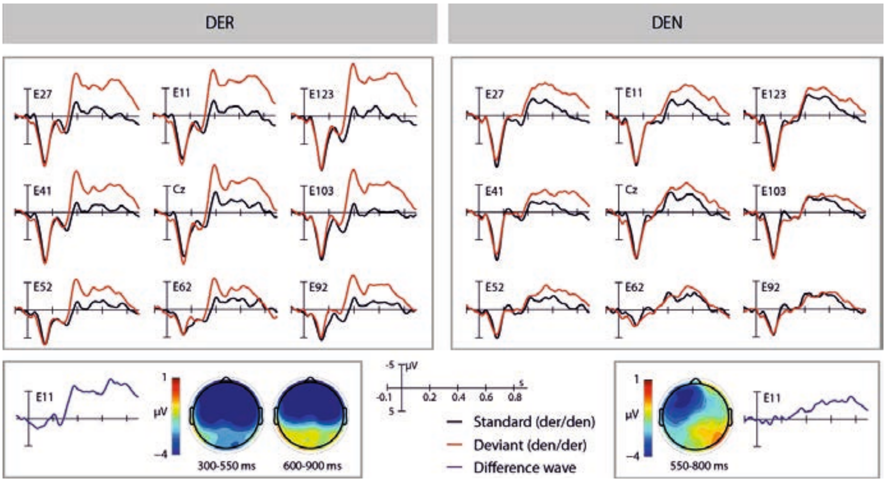

Figure 3.3.3. ERP response to the standard (in black) and deviant (in red) separately for *der* and *den* elicited in 2-year-olds. For voltage topographies mean amplitudes between given latencies were calculated at deviant-minus-standard difference wave (in blue). Negativity is plotted upwards.

The main effect of Stimulus Type for the article *der* was significant between 300–850 ms (Table 3.3.2). Additionally, the analysis of the interactions in the anterior-posterior plane between 400–550 ms and 650–900 ms revealed that the amplitude differences were at largest in fronto-central areas. In posterior areas, they were present for the first negativity, but reduced to 600–700 ms for the second negativity. Based on these results, the peaks of mismatch responses were defined in the TWs 300–550 ms and 550–900 ms for early and late negativity, respectively. The mean peak amplitude of the early mismatch response to *der* was -8.90 µV (*SD* = 3.96 µV). The peak was observed at the latency of 412 ms (*SD* = 66 ms), that is, 254 ms post-deviance. The late mismatch response peaked at 718 ms (*SD* = 81 ms), that is, at 560 ms post-deviance, with the amplitude of -9.94 µV (*SD* = 5.10 µV).

Table 3.3.2. Analysis of variance as calculated in Experiment 1b in 2-year-old children for comparison: standard *der* versus deviant *der*.

TW	**Main effect of stimulus type *F*(1, 14)**	**Type × AP (df) F**	**Type × AP Resolved**		
			ANT	**CENT**	**POST**
300–350	12.73**				
350–400	33.95*				
400–450	24.43*	(1.36, 19.08) 6.01*	22.84**	18.85**	10.88**
450–500	16.83**	(1.37, 19.15) 7.66**	20.01**	12.66**	5.27*
500–550	16.35**	(2, 28) 4.37*	15.89**	13.16**	6.17*
550–600	15.14*				
600–650	17.61*	(1.29, 18.06) 4.43*	16.82**	15.50**	5.84*
650–700	22.46**	(1.33, 18.64) 11.14*	28.91**	18.66**	6.74*
700–750	17.39**	(2, 28) 23.02**	28.64**	18.07**	-
750–800	13.33**	(1.38, 19.35) 18.18**	25.30**	12.91**	-
800–850	10.00**	(1.32, 18.52) 13.80**	9.05**		
850–900		(1.46, 20.38) 12.21**	11.07**		

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior. p ≤ 0.01**, 0.01 < p ≤ .05*.

In case of *den*, no early mismatch negativity was observed. The negative deflection started at approximately 400 ms (Figure 3.3.3, right panel). This was confirmed by the analysis of variance (Table 3.3.3) that revealed the main effect of Stimulus Type between 600–800 ms.

Additionally, a Stimulus Type × LP interaction was found between 550–600 ms. The analysis of this interaction confirmed the left-lateralized distribution of the effect that can be seen in Figure 3.3.3 (right panel) at the initial stage of the late negativity. The analysis of the TW 750–800 ms showed an interaction of the factor Stimulus Type with the distributional factor in anterior-posterior plane. In this time range, the effect was present in anterior and central areas. Thus, the peak characteristics of the late negativity were quantified in time window 550–800 ms. The late mismatch response to the deviant *den*, as measured at the Fz electrode, peaked at 664 ms (*SD* = 85 ms) after the stimulus onset, that is, at 506 ms post-deviance, with the amplitude of -6.49 µV (*SD* = 3.88 µV).

Table 3.3.3. Analysis of variance as calculated in Experiment Ib in 2-year-old children for comparison: standard *den* versus deviant *den*.

TW	**Main effect of stimulus type *F*(1, 14)**	**Type × AP (df) F**	**Type × AP Resolved**		**Type × LP (df) F**	**Type × LP Resolved**	
			ANT	**CENT**		**LEFT**	**MID**
550–600					(2, 28) 3.60*	10.85**	4.76*
600–650	4.59*						
650–700	4.86*						
700–750	5.91*						
750–800	8.34*	(2, 28) 4.88*	11.82**	9.23**			

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane; ANT, anterior; CENT, central; LEFT, left; MID, midline. p ≤ 0.01**, 0.01 < p ≤ .05*.

The amplitude of the late mismatch response to *den* at the Fz electrode was significantly smaller than the amplitude of the late negativity elicited by *der*, as assessed by the paired-sample t-test (*t*(14) = -2.60, *p* = .021). The late mismatch responses did not differ in terms of latency (*t*(14) = 1.89, *p* = .080, Figure 3.3.4).

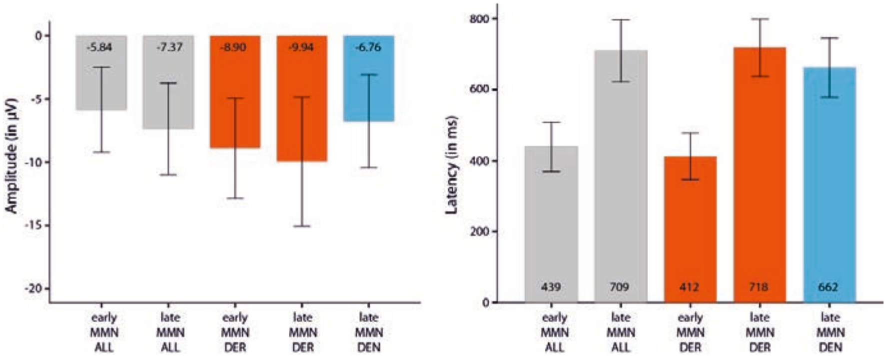

Figure 3.3.4. Mean amplitudes and latencies of the mismatch responses for all articles (in grey), *der* (in red) and *den* (in blue) in 2-year-olds. Latency values are plotted in relation to stimulus onset. Error bars indicate one standard deviation.

Discussion

In Experiment 1b we tested the ability of 2-year-old children to differentiate between determiners *der* and *den* in an oddball paradigm. Our participants were presented with both forms in both conditions (standard versus deviant) within one experimental session. This allowed for a comparison of the auditory discrimination capacities for both articles by reducing the impact of physical differences on the mismatch response.

The first mismatch negativity to *der*/*den* peaked at 281 ms after the point of stimulus deviation. This result was comparable with the results of the Experiment 1a, as well as with the findings of the previous studies in children, in which early mismatch negativities to speech contrasts were observed between 220–560 ms (Čeponienė et al., 2003; Niemitalo-Haapola et al., 2013; Shafer et al., 2010; Uwer & von Suchodoletz, 2000). This finding was also consistent with literature on processing of tone contrasts in 2-year-olds, in which MMN typically peaked earlier between 120–260 ms (Glass, Sachse, & von Suchodoletz, 2008a; Glass et al., 2008b; Morr et al., 2002; Putkinen, Niinikuru, Lipsanen, Tervaniemi, & Huotilainen, 2012).

The second mismatch response peaked at 551 ms post-deviance, that is, approximately 20 ms later than LDN in the study on vowel processing in 3-year-olds by Čeponienė et al. (2003), and 100 ms later than LDN to consonant contrasts in 7- to 12-year-old children in the study by Bishop et al. (2011). These differences might be explained by two factors. As discussed in the previous *Discussion* section (Chapter 3.2), our stimulus items were naturally spoken words that differed in several features, including the acoustic characteristics of the vowel and phonemic characteristics of the final consonants. In contrast, studies mentioned above tended to manipulate one acoustic feature in stimulus material. Thus, the complexity of the stimulus material that we used in the current experiment might have had an effect on the prolonged late response in 2-year-olds. On the other hand, the obtained late negativity reflects the tendency of LDN to occur earlier with increasing age. In sum, the reported negativities are in agreement with existing literature on auditory processing of speech stimuli in children. They indicate that 2-year-old children are able to differentiate between naturally pronounced articles *der* and *den*.

The mismatch response patterns elicited by determiners *der* and *den* were different in terms of their latencies and topographies. While *der* produced a biphasic response consisting of two negativities, only late negativity was observed for determiner *den*. The amplitude of the late negativity to *den* was significantly smaller than that to the determiner *der*. This asymmetry can be discussed at multiple levels of linguistic analysis that implicate the contribution of acoustic and lexical factors to MMN.

Determiners *der* and *den* were compared separately in both conditions to reduce the impact of acoustic differences on the mismatch negativity. This did not exclude, however, that a change of acoustic parameters in a standard-deviant sequence, such as increment/decrement of acoustic frequency, intensity, duration, had no effect on the pattern of the ERP response. Earlier studies showed the sensitivity of mismatch negativity to the direction of frequency change in tone sequences in adults. Frequency increment between the standard and the deviant item was reported to produce MMN of greater amplitude than frequency decrement (Karanasiou et al., 2011; Peter, McArthur, & Thompson, 2010). Present stimuli were matched for the overall duration, intensity and fundamental frequency. Nevertheless, the natural acoustic complexity of two spoken words, as reflected, among others, by the behavior of frequency formants F1, F2, F3 and F4, might have contributed to the distinct MMN patterns to *der* and *den*. The formant values in the present stimulus materials reflected the natural acoustic-articulatory relationship. To our knowledge, no study investigated the auditory change detection in complex frequency structures. Thus, one cannot exclude the sensitivity of the MMN system to the changes of complex frequency parameters of natural speech.

Furthermore, the determiner-specific ERP patterns might be due to the discrepancies in the length of the stable vowel [ɛ] that was approximately 30 ms longer in *den*. The decrement of vowel duration in the sequence *den-der* was associated with two negativities. Duration increment in the sequence *der-den* was related to a late sustained negativity. However, studies that examined duration deviance using complex speech stimuli in children showed that longer deviants elicit a typical early mismatch response. For example, duration increment triggered two mismatch negativities in Finnish sleeping newborns that were presented with complex speech stimuli /asa/ and /assa/ (Kushnerenko et al., 2001). The first negativity peaked at about 150 ms and was also observed in one of the conditions in which infants were exposed to the consonant duration decrement of 160 ms. The second negativity peaked at about 350 ms and was evident for all duration deviances. In 2-month-old infants, long vowel deviants showed a positive mismatch response followed by a frontal negativity, whereas short vowel deviants elicited only a negativity (Friederici, Friedrich, et al., 2002). Also, preschool (mean age 5;4 years) and school Finnish children (mean age 9;3 years) in the study by Partanen, Torppa, Pykäläinen, Kujala, and Huotilainen (2013) showed a statistically significant MMN to vowel duration increment of 80 ms in a word context for standard /tatata/ and deviant /tata:ta/. Taken together, these findings indicate that duration increment in speech stimuli triggers mismatch response from early age. Thus, the acoustic discrepancies in vowel length can hardly explain the MMN pattern obtained in the current study with children.

On the other hand, the observed effects cannot be explained by differences in sparse neural code for consonants (Lahiri & Reetz, 2010), as it was suggested, for example, within the predictive account of MMN by Scharinger, Bendixen, Trujillo-Barreto, and Obleser (2012). If an abstract property such as place of articulation guided predictive processes in the oddball paradigm, a more specific consonant would elicit a greater mismatch response than a less specific consonant, as it was reported in their study for the coronal [t] and dorsal [k]. Our results contrast these findings, since the coronal [n] elicited a smaller negativity than the dorsal approximant [ʁ].

At the lexical level, the enhancement of the mismatch response to *der* might be explained by the greater familiarity of determiner *der* to German-acquiring children, as reflected by its high occurrence frequency. The corpus-based analysis of German data showed that *der* occurs twice more frequent than *den* in spontaneous speech of 2- and 3-year-old children. This result was in agreement with the observations on the developmental trajectory of the article acquisition, following which children start to produce *der* earlier than *den* (Szagun, 2006). Thus, children at the age of two are more familiar with the form *der* than to the form *den*. Frequency effects have been recently shown to modulate the amplitude of mismatch response in adults (Alexandrov et al., 2011; Leminen et al., 2013; MacGregor & Shtyrov, 2013; Shtyrov et al., 2011). The enhancement effect for high-frequent words was distributed at left frontal (Shtyrov et al., 2011), fronto-central (Leminen et al., 2013), and central electrodes (MacGregor & Shtyrov, 2013). These results were explained by the stronger co-activation of cell assemblies for words than for non-words, and for frequently used words than for infrequently used words (Pulvermüller, 1999). Our results are consistent with the findings on word frequency effects. More frequent determiner *der* elicited a greater early negativity with the fronto-central distribution in 2-year-olds. Therefore, the pattern of the mismatch response to *den* might be due to its low familiarity in comparison to *der*.

Experiment 1b showed that two-year-old children are able to auditorily discriminate between naturally spoken determiners *der* and *den*, as indexed by the mismatch negativity. Its latency and amplitude were comparable with the findings of previous studies that explored MMN to speech and non-speech contrasts in children. Separate analysis of the response to acoustic change for each article showed two distinct patterns: while *der* produced a biphasic response, only one negativity was observed for *den*. These discrepancies were explained by acoustic and lexical factors.

3.4 Experiment 1c: 3-year-old children

Experiment 1c aimed to explore the discriminative abilities of 3-year-old children. The paradigm of the MMN experiment was modified to account for the global MMN refractoriness, that is, a dynamic change of the MMN amplitude during the recording session. Studies on habituation effects in oddball paradigms showed the increase of MMN refractoriness in the course of the experiment in 3-year-old children (Čeponienė et al., 2003), 6- to 14-year old children, adults, and guinea pigs (McGee et al., 2001). Crucially, Čeponienė et al. (2003), who explored the MMN to the vowel contrasts in small children, showed that the amplitude of the negativity to the cross-category contrast /a – o/ diminished significantly between 10-14th minutes of the experimental recording over the frontal electrodes. The amplitude of the mismatch response to the between-category contrast /a – ã/ showed the same tendency. These results indicate that the MMN refractoriness increases during the course of recording. To reduce the global MMN refractoriness and increase the signal-to-noise ratio, block alternation was introduced into the current design.

Based on the findings of previous studies and results of Experiments 1a and 1b, we hypothesized that

- 3-year-old children discriminate automatically between the articles *der* and *den*, as reflected by the mismatch response between 120 and 300 ms post-deviance (Glass et al., 2008b; Putkinen et al., 2012);
- the mismatch response is followed by a late negativity between 300–600 (Čeponienė et al., 2003; Kraus et al., 1993);
- the patterns of mismatch negativity differ for *der* and *den*: the amplitude of the mismatch response to low-frequency item *den* is expected to be lower than the amplitude to the high-frequency item *der* (Alexandrov et al., 2011).

Methods

Participants

Sixty three-year-old children participated in the Experiment Ic (age range 37–48 months, M_{age} = 41.67 months, *SD* = 3.36 months, 36 girls). Informed parental consent was obtained for all children before the experiments. Four children were excluded due to the neurological disease history, and one due to the bilingual environment. Nine participants did not provide enough data. Thus, the final analysis included forty-six children (age range 37–48 months, M_{age} = 41.57 months, *SD* = 3.46 months, 27 girls). The mean laterality quotient, as assessed by the child-adapted version of the Edinburgh Handedness Inventory Materials (Oldfield, 1971) was 54% (*SD* = 41%). Handedness measurements were not possible in two children.

Materials

Experiment 1c used the same recorded items as Experiments 1a and 1b. Experiment 1c consisted of four blocks, in which standards and deviants were alternating. While *der* functioned as a standard in two blocks, *den* was established as a standard in the other two blocks, as shown in Figure 3.4.1. The duration of the Experiment 1c was approximately 20 minutes. A break was included if it was necessary. The stimulus items were presented with a fixed ISI of 500 ms from offset to onset of the next item in a pseudorandomized order. This design allowed for a within-subject comparison of a single item in both standard and deviant conditions.

The order of the stimulus presentation in Experiment 1c was counterbalanced across the participants. For the half of them, the experiment started with the block in which *der* was maintained as a standard. Another half of participants initially received the block with *den* as a standard stimulus. The probability of occurrence of the standard and deviant items was 83% and 17%, respectively. Five to seven standard items preceded each deviant. Each block started with the presentation of ten standard stimuli that were not included into further analysis.

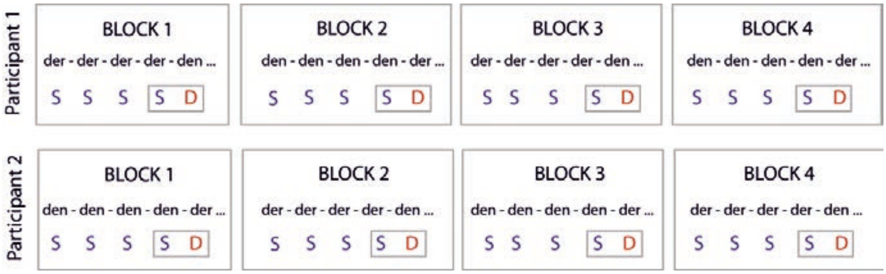

Figure 3.4.1. Design of the Experiment 1c. Standards are marked with S, deviants are marked with D. The S-D pair illustrates the items that were included into the analysis of the difference wave.

For Experiment 1c, epochs containing standard *der*, standard *den*, deviant *der*, and deviant *den* were averaged separately to build ERPs. Thus, the influence of the acoustic features of the stimuli could be minimized in Experiment 1c.

Procedure

The procedure for the experiment was the same as in Experiment 1a/1b with 2-year-old children. Instead of the cartoon “The flower” (Kerp, 2001) a shortened salient version of “Bolek and Lolek: In the forests of Canada” (Nehrebecki, 1968) was used along with the film “The mole and the little hare” (Miler, 1997) to keep children still and quite.

EEG recording

The EEG recordings were made with the same parameters as in 2-year-old children.

Data analysis

Data processing and statistical analyses were conducted with the same parameters as in 2-year-old children. The retention rate was higher for 3-year-old. Only 9 (14%) of 63 individual averages had to be excluded from the grand average due to the poor quality of the data.

Results

Deviants elicited two clearly defined negativities in 3-year-old children: an early negativity starting at around 300 ms after stimulus onset, and a late negativity between 550–900 ms (Figure 3.4.2).

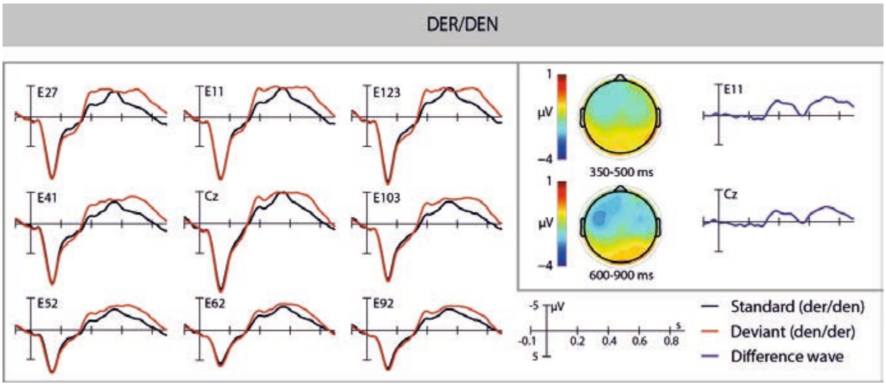

Figure 3.4.2. ERP response to the standard (in black) and deviant (in red) elicited in 3-year-olds. For voltage topographies mean amplitudes between given latencies at deviant-minus-standard difference wave (in blue) were calculated. Negativity is plotted upwards.

The early negativity was statistically significant between 350–500 ms, as reflected by the main effect of factor Stimulus Type in this time window (Table

3.4.1). No interactions with distributional factors AP or LP were found. ANOVA for the second negativity showed a main effect of Stimulus Type between 600–900 ms, as well as significant Stimulus Type × AP interaction in the last 200 ms of the epoch. The amplitude of the MMN was larger in anterior-central areas, with exception of the time period 700–800 ms, in which the main factor of Stimulus Type was significant also in posterior regions. Thus, two time windows were chosen to define the peak of the mismatch response: 350–500 ms and 600–900 ms. The early negativity peaked at 419 ms (*SD* = 47 ms) after stimulus onset with the mean amplitude of -3.59 µV (*SD* = 4.01 µV). That is, its peak was at 261 ms relative to the point of deviance. The late negativity peaked at 741 ms (*SD* = 81 ms), that is, at 583 ms post-deviance. The mean amplitude of the late mismatch response was -4.96 µV (*SD* = 3.83 µV, see Figure 3.4.4 for the summary of mean latencies and mean amplitudes in 3-year-olds).

Table 3.4.1. Analysis of variance as calculated in Experiment 1c in 3-year-olds: standard *der/den* versus deviant *den/der*.

TW	**Main effect of stimulus type *F*(1, 45)**	**Type × AP (df) F**	**Type × AP Resolved**		
			ANT	**CENT**	**POST**
350–400	21.11**				
400–450	19.41**				
450–500	11.07**				
600–650	11.62**				
650–700	20.55**				
700–750	24.59**	(1.28, 57.71) 7.79**	23.26**	22.26**	8.16**
750–800	17.92**	(1.28, 57.60) 6.54**	16.12**	18.31**	4.72*
800–850	11.71**	(1.25, 56.44) 6.46**	13.08**	11.86**	-
850–900	7.13*	(1.23, 55.45) 6.21*	9.78**	7.61**	-

Note. TW, time window; AP, anterior-posterior plane; ANT, anterior; CENT, central; POST, posterior. p ≤ 0.01**, 0.01 < p ≤ .05*.

The mismatch negativities elicited by *der* and *den* had different patterns. As compared to the standard *der*, the deviant *der* elicited two negativities: an early negativity between 300–550 ms and a late negativity between 600–900 ms (Figure 3.4.3, left panel).

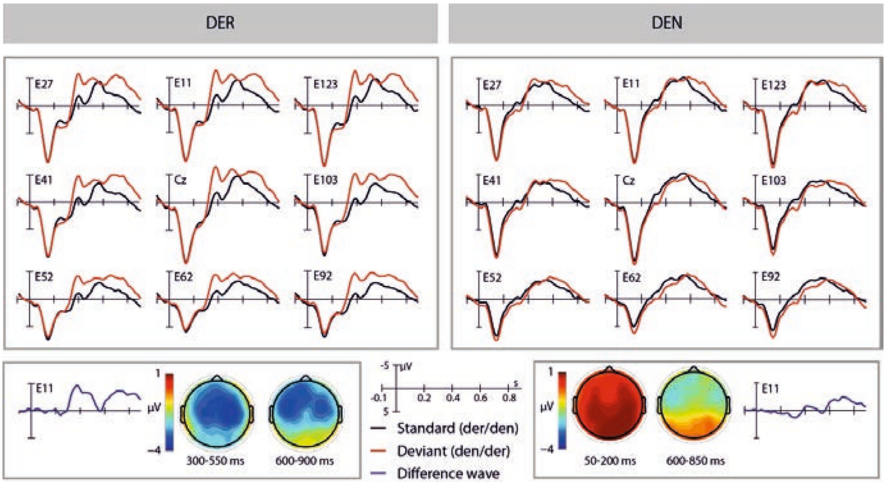

Figure 3.4.3. ERP response to the standard (in black) and deviant (in red) elicited in 3-year-olds separately for *der* and *den*. For voltage topographies mean amplitudes between given latencies at deviant-minus-standard difference wave (in blue) were calculated. Negativity is plotted upwards.

For the determiner *der*, repeated measures ANOVA revealed the main effect of factor Stimulus Type in time periods 300–550 ms and 600–900 ms (Table 3.4.2). In the TW 200–250, the interaction Stimulus Type × AP was significant (*F*(1.27, 57.10) = 4.83, *p* = .024), but no distributional patterns of the effect were revealed by ANOVA. In two TWs between 300–400 ms, an interaction Stimulus Type × LP was found that, however, did not indicate any hemisphere-specific distributions of the MMN. Interactions Stimulus Type × AP were significant during the course of the late negativity between 700–900 ms. The step-down analysis of these interactions showed area-specific distributions only in the last time window 850–900 ms, in which the effect was larger in anterior-central areas but not in posterior area (*F*(1, 45) = 3.16, *p* = .082). Thus, two TWs were chosen for the quantification of MMN to *der* in 3-year-olds: 300–550 ms and 600–900 ms. The early mismatch response peaked at the latency of 416 ms (*SD* = 65 ms) after stimulus onset, that is, at 258 ms after the point of physical deviation. Its mean amplitude was -6.84 μV (*SD* = 5.18 μV). The mean latency of the late MMN peak was 746 ms (*SD* = 82 ms) after the stimulus onset, that is, at approximately 588 ms post-deviance. The late MMN peaked with amplitude of -6.73 μV (*SD* = 4.28 μV) at the Fz electrode.

Table 3.4.2. Analysis of variance as calculated in Experiment 1c in 3-year-olds: standard *der* versus deviant *der*.

TW	Main effect of stimulus type *F*(1, 45)	Type × AP	Type × AP Resolved			Type × LP	Type × LP Resolved		
			ANT	CENT	POST		LEFT	MID	RIGHT
300–350	14.43**					(1.73, 77.66) 3.51*	9.72**	15.80**	13.84**
350–400	53.55**	(1.32, 59.59) 4.33*	35.95**	50.59**	37.68**	4.16*	35.08**	53.29**	51.76**
400–450	37.99**								
450–500	30.91**								
500–550	7.42**								
600–650	11.11**								
650–700	24.11**								
700–750	29.69**	6.09*	23.60**	27.68**	13.01**				
750–800	24.57**	5.07*	17.73**	24.01**	10.82**				
800–850	19.50**	4.56*	16.09**	17.84**	6.90*				
850–900	14.08**	4.89*	13.44**	13.29**	-				

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane; ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, middle; RIGHT, right. p ≤ 0.01**, 0.01 < p ≤ .05*.

As can be seen in Figure 3.4.3 (right panel), deviant determiner *den* elicited an early positivity between 100–200 ms and a late negativity between 600–800 ms.

Table 3.4.3. Analysis of variance as calculated in Experiment Ic in 3-year-olds: standard *den* versus deviant *den*.

TW	Main effect of stimulus type *F*(1, 45)	Type × AP (*df*) F	Type × AP Resolved			Type × LP (*df*) F
			ANT	CENT	POST	
50–100	5.20*					
100–150	5.28*					
150–200	4.18*					
300–350	7.14*					
400–450		(1.26, 56.64) 4.87*	-	-	5.13*	(1.73, 77.88) 3.62*
600–650	5.85*					
650–700	7.33*					
700–750	7.79**	(1.31, 58.96) 5.25*	10.10**	7.70**	-	
750–800	4.97*	(1.31, 59.08) 5.58*	7.42**	6.11*	-	
800–850		(1.33, 59.67) 7.34**	5.29*	-	-	
850–900		(1.26, 56.52) 6.73**				(1.72, 77.26) 3.69*

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane; ANT, anterior; CENT, central; POST, posterior. p ≤ 0.01**, 0.01 < p ≤ .05*.

Statistical analysis confirmed the presence of significant differences between conditions in early (50–200 ms) and late (600–900 ms) time windows (Table 3.4.3). Specifically, the main effect of Stimulus Type was found between 50–200 ms and 600–800 ms. The main effect was also evident in time window 300–350 ms, but not in adjacent TWs 250–300 ms and 350–400 ms. Similarly, the positivity was distributed in the posterior areas in TW 400–450 ms, but no effects were found in the neighboring time intervals 350–400 ms and 450–500 ms.

Stimulus Type × AP interactions were significant in time intervals between 700–900 ms. These were driven by the strength of effect in anterior and central areas in time interval 700–850 ms. The step-down analysis of the factor Stimulus Type in the lateral plane did not reveal any hemisphere-specific distributions.

Based on the results of the statistical analysis, the time interval 600–850 ms was chosen for quantification of the mismatch negativity response. It peaked at 719 ms (*SD* = 76 ms) after the stimulus onset, that is, at approximately 561 ms after the point of acoustic change. The amplitude of this response was -4.59 µV (*SD* = 4.67 µV, see Figure 3.4.4 for a summary of the mean amplitudes and latencies).

Similar to the late MMN in 2-year-olds, the amplitude of the late negativity elicited by *den* was significantly smaller than the amplitude of the late negativity elicited by *der* ($t(45) = -3.40$, $p = .001$). Their latencies did not differ ($t(45) = 1.61$, $p = .114$).

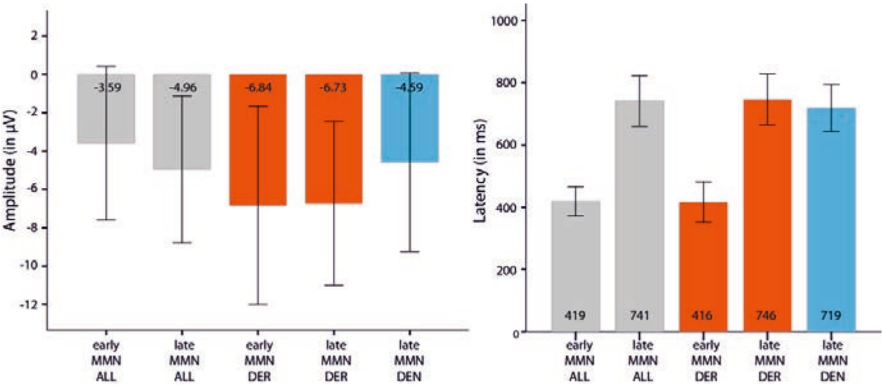

Figure 3.4.4. Mean amplitudes and latencies of the mismatch responses for all articles (in grey), *der* (in red) and *den* (in blue) in 3-year-olds. Latency values are plotted in relation to stimulus onset. Error bars indicate one standard deviation.

Discussion

Experiment 1c explored the ability of 3-year-old children to acoustically differentiate between two naturally-spoken determiner forms *der* and *den*, as reflected by the mismatch negativity. In the oddball paradigm, deviants (either *der* or *den*) elicited two negativities. While the early negativity peaked at 261 ms after the deviance point, the local peak of the late negativity was observed at 583 ms post-deviance. These results accord with previous studies on speech and tone discrimination in preschool children. For example, the mismatch response to vowel contrasts in 3-year-olds in the study by Čeponienė et al. (2003) peaked between 300–400 ms with the amplitude between -3.80 and -4.90 µV. In 3- to 7-year-old children, the mismatch response to consonant contrast /da – ba/ peaked at 271 ms (Paquette et al., 2013). Non-speech stimuli elicited a mismatch negativity between 120–260 ms (Putkinen et al., 2012) and 132–248 ms (Glass et al., 2008b) in 3-year-olds. Similarly, results on the late negativity are consistent with the findings of the study by Čeponienė et al. (2003): the MMN to vowel contrasts was associated with an LDN peaking between 510–530 ms. Taken together, the results of our experiment are in accordance with a few studies that examined sound discrimination in 3-year-olds. These findings indicate that 3-year-olds are able to discriminate between *der* and *den* in an oddball paradigm.

Similar to the mismatch response obtained in our youngest group (see Chapter 3.3), *der* and *den* elicited different MMN patterns. Deviant *der* produced two negativities: an early negativity (peak 258 ms post-deviance) and a late negativity (peak 574 ms post-deviance). In contrast, deviant *den* showed only one negativity that peaked 588 ms after the point of physical deviation. There is a number of factors that might explain these results.

Similar to the data of 2-year-olds, the discrepancies in the MMN responses to determiners *der* and *den* might be attributed solely to the complex acoustic parameters of the experimental stimuli. The potential parameter is increment/decrement of each formant frequency (F1–F4) between standard and the following deviant (Jacobsen & Schröger, 2001; Karanasiou et al., 2011; Peter et al., 2010; Scharinger et al., 2012). However, the ERP asymmetry can be hardly explained by differences in duration of the stable vowel [ɛ] in *den* and in *der*. In contrast to our data for *der-den* sequence, duration increment in speech stimuli was shown to elicit early mismatch responses in children (Friederici, Friedrich, et al., 2002; Kushnerenko et al., 2001; Partanen et al., 2013).

Second, the observed discrepancies in MMN to *der* and *den* could be attributed to the different degrees of familiarity of the determiner forms to 3-year-old children (see also section *Discussion* in Chapter 3.3). In a series of studies that explored the effect of occurrence frequency on the amplitude of the MMN, the more frequently used word elicited a response of greater amplitude than a less frequently used word (Alexandrov et al., 2011; Leminen et al., 2013; Shtyrov et al., 2011). Enhancement of the MMN amplitude was reported in a number of studies that explored neural plasticity, as accompanying laboratory training in speech sound discrimination in adults (Kraus et al., 1995) and natural exposure to foreign language in pre-school children (Cheour, Shestakova, et al., 2002; for review, see Näätänen, 2008). Taken together, these studies indicated that language experience, as reflected by the frequency of use of a certain word or exposure to a sound pattern, might have impact on the properties of the mismatch response. In line with these findings, the more frequent form *der* elicited an earlier response than the less frequent form *den* in the current study. Therefore, the usage-related characteristics of the determiner forms might affect children's ability to discriminate between articles and modulate the mismatch response.

The purpose of the present experiment was to explore the ability of 3-year-old children to auditorily discriminate between naturally spoken determiners *der* and *den*. The results of the analysis show that children are able to discriminate between the two determiners, as reflected by an age-typical mismatch response that was elicited in the oddball paradigm. It was also shown that the processing of acoustic changes for individual determiners is associated with distinct MMN patterns. These discrepancies were attributed to acoustic and lexical factors.

3.5 Experiment 1d: Adults

Experiment 1d aimed at exploring the auditory discrimination between the naturally-spoken determiners *der* and *den* in adults. It sought to obtain data that allow to assess the developmental profile for acoustic processing of syntax-relevant speech items. Based on the previous studies of mismatch response in adults and analysis of MMN in Experiments 1a–1c, we hypothesized that

- adults pre-attentively discriminate between determiners *der* and *den*, as indexed by the mismatch response between 130–250 ms after the deviance onset, that is, approximately 288–408 ms from stimulus onset (Näätänen, 2001; Näätänen et al., 2007; Pulvermüller & Shtyrov, 2006);
- deviants either elicit a small or no late discriminative negativity (Bishop et al., 2011; Kraus et al., 1993);
- the morphology of the mismatch negativity to *der* and *den* diverge: the average peak amplitude of the MMN to the high-frequent item *der* is expected to be greater than the amplitude of the MMN to the low-frequent item *den* (Alexandrov et al., 2011).

Methods

Participants

Thirty-four adults took part in the experiment (age range 21–35 years, M_{age} = 27.32 years, *SD* = 3.70 years, 15 female). All of them were German native speakers recruited from the database of Max Planck Institute for Cognitive and Brain Sciences, Leipzig. None of them reported any auditory and/or neurological diseases. Mean laterality quotient was 88% (range 50–100%, *SD* = 16%), as assessed by the German version of the Edinburgh Handedness Inventory (Oldfield, 1971). Their cognitive abilities were evaluated by a subtest *Figure sequences* of the intelligence test *Leistungsprüfsystem-3* (Horn, 1983). *Figure sequences* subtest on logical reasoning measures only one aspect of intelligence. However, its results correlate strongly with the performance on the whole test (r = .85). The mean intelligence score in the current sample was 119.53 (range 108–134, *SD* = 8.04).

Adult participants completed all the EEG experiments and psychometric tests in one session. The order of the EEG measurements was counterbalanced within the group so that a half of adults were first presented with the articles in the auditory discrimination experiment, followed by the sentence processing study.

The second half of adults initially took part in the sentence processing experiment. Participants were not involved into any other project related to the current study. They were paid 21 Euro for the session.

Materials

Experiment 1d used the same stimuli recordings as Experiments 1a-1c with children (for detailed description of the materials, see section *Materials* of Chapter 3.2). Experimental design was identical to that of the Experiment 1c with 3-year-old children. It consisted of four blocks, in which *der* and *den* were alternating as standards and deviants (for details, see section *Methods* of Chapter 3.4).

Procedure

Adults were tested in the same laboratory setup as 2-year-old and 3-year-old-children (see section *Procedure* of Chapter 3.2). They were seated in a comfortable chair in front of the VGA monitor (Sony, Tokyo, Japan) and Bowers & Wilkins loudspeakers (B&W Group Germany GmbH, Halle, Germany) at 110 cm distance. Adults were instructed not to pay attention to the stimulus material but to watch the cartoon quietly. The films "Bolek and Lolek: In the forests of Canada" (Nehrebecki, 1968) and "The mole and the little hare" (Miler, 1997) were presented.

EEG recording

Electrophysiological data recordings were performed with the same parameters as in children (see section *EEG recording* of Chapter 3.2).

Data analysis

Data processing algorithms were similar to those used for children's data. ICA-based algorithms were used to correct stereotyped artefacts, such as eye blinks, horizontal eye movements and muscle activity (for details, see Appendix D). Epochs with remaining non-stereotyped artefacts were rejected automatically. In contrast to children's data analysis, the thresholds for the automatic rejection were lowered to 100 µV for absolute value rejection, and to 5 *SDs* for probability-based rejection. All the datasets had enough data (> 75% of trials) to be included into the grand average.

Results

As can be seen in Figure 3.5.1, deviants have elicited a mismatch negativity response between 200–400 ms with a peak around 300 ms in adults.

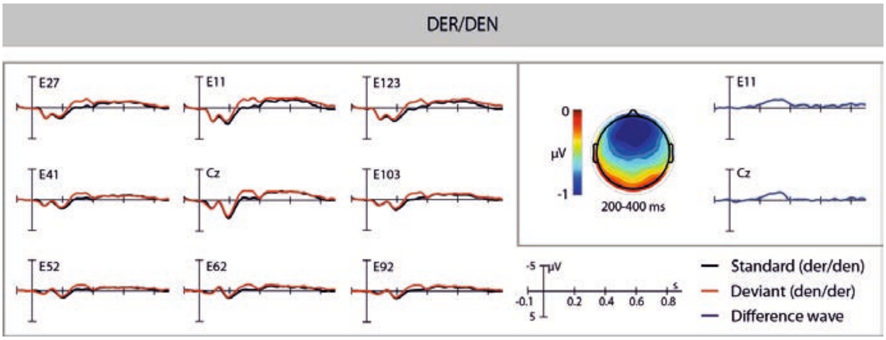

Figure 3.5.1. ERP response to the standard (in black) and deviant (in red) elicited in adults. For voltage topographies mean amplitudes between given latencies were calculated at deviant-minus-standard difference wave (in blue). Negativity is plotted upwards.

This observation was confirmed by the analysis of amplitudes in the consecutive 50-ms TWs that revealed the main effect of Stimulus Type between 200 and 400 ms (Table 3.5.1). Interaction Stimulus Type × AP was significant between 200–400 ms. The effect was present in anterior and central regions in the time period 200–400 ms, but also in posterior area between 250–350 ms.

In TW 300–350 ms, an interaction Stimulus Type × LP was found, but no hemisphere-specific distributions were observed. An interaction Stimulus Type × AP × LP was also significant in this TW ($F(4, 132) = 2.78$, $p = .03$, not reported in Table 3.5.1). The step-down analysis of the interaction showed that the effect was significant in all nine regions of interest ($F(1, 33) = 9.47$–28.83, $p < .004$).

Thus, the time period 200–400 ms was chosen for quantification of mismatch negativity in adults. Its mean amplitude at Fz was -2.29 µV (*SD* = 1.50 µV). The negativity peaked at 307 ms (*SD* = 52 ms) after stimulus onset, that is, at 149 ms after the point of deviation (see Figure 3.5.3 at the end of this section for a summary of results).

Table 3.5.1. Analysis of variance as calculated in Experiment 1d in adults: standard *der/den* versus deviant *den/der*.

TW	**Main effect of stimulus type *F*(1, 33)**	**Type × AP (df) F**	**Type × AP Resolved**			**Type × LP (df) Fz**	**Type × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
200–250	9.40**	(1.36, 44.84) 5.73*	10.66**	7.57**	-				
250–300	23.50**	(1.31, 43.38) 10.79**	24.29**	22.53**	6.33*				
300–350	28.53**	(1.35, 44.45) 11.21**	26.03**	27.24**	7.28**	(1, 33) 14.99**	24.16**	25.89**	31.26**
350–400	15.84**	(1.33, 43.74) 6.68**	17.12**	9.95**	-				

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane; ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, middle; RIGHT, right. $p \leq .01$**, $.01 < p \leq .05$*.

Similar to children's ERP, the mismatch response patterns differed between *der* and *den* (Figure 3.5.2). *Der* elicited a fast negativity between 150–400 ms peaking at around 300 ms after stimulus onset, whereas *den* showed a sustained negativity starting at approximately 200 ms without clear peak.

ANOVA results confirmed this observation (Table 3.5.2). For the determiner *der*, the main effect of Stimulus Type was found between 100–350 ms. Similar effects were observed in several discrete TWs 400–450 ms, 500–550 ms, 600–650 ms that were excluded from the further analysis of mismatch response to *der*. In TW 100–150 ms, an interaction Stimulus Type × AP × LP was observed (*F*(3.08, 101.65) = 3.25, *p* = .024) that revealed region-specific distribution of the effect in anterior (*F*(1, 33) = 5.00–9.35, *p* = .004–.033) and central (F(1, 33) = 6.86–14.71, *p* = .001–.013) clusters, as well as in the posterior-left region (*F*(1, 33) = 6.31, *p* = .017). Furthermore, interactions with the LP factor were found between 150–350 ms. The effect was distributed in left and middle clusters in all TWs between 150–350 ms, but also in the right cluster in TWs 200–250 ms, 250–300 ms, 300–350 ms.

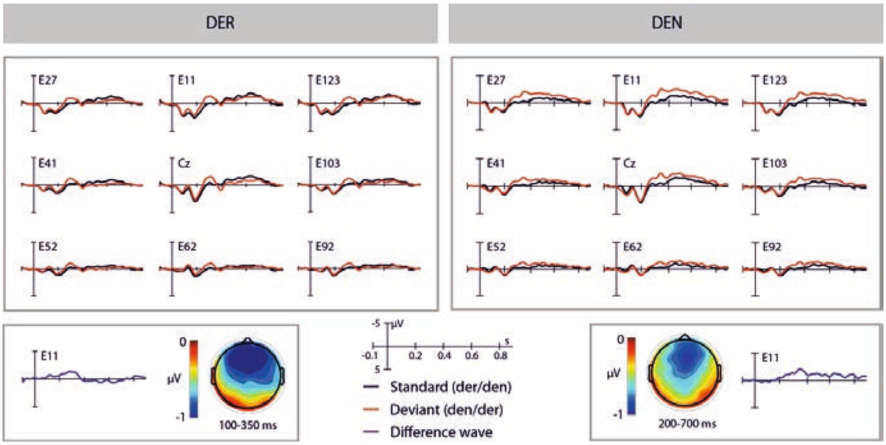

Figure 3.5.2. ERP response to the standard (in black) and deviant (in red) separately for *der* and *den* elicited in adults. For voltage topographies mean amplitudes between given latencies were calculated at deviant-minus-standard difference wave (in blue). Negativity is plotted upwards.

Table 3.5.2. Analysis of variance as calculated in Experiment 1d in adults: standard *der* versus deviant *der*.

TW	**Main effect of stimulus type** ***F*(1, 33)**	**Type × LP (df) F**	**Type × LP Resolved**		
			LEFT	**MID**	**RIGHT**
100–150	13.83**				
150–200	7.33*	(2, 66) 3.80*	8.06**	8.32**	-
200–250	10.66**	(2, 66) 4.43*	11.13**	11.70**	6.11*
250–300	19.92**	(2, 66) 4.04*	17.77**	18.13**	19.67**
300–350	14.68**	(2, 66) 4.17*	11.81**	13.83**	14.78**
400–450	4.29*				
500–550	5.82*				
600–650	8.98**				

Note. TW, time window; LP, lateral plane; LEFT, left; MID, middle; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*.

Thus, TW 100–350 ms was chosen for MMN quantification for determiner *der*. The mismatch response peaked at 260 ms (*SD* = 69 ms) after the onset of determiner, that is, 102 ms after the point of deviance. Its amplitude at the Fz electrode was -2.94 µV (*SD* = 1.37 µV).

Determiner *den* elicited a sustained negative deflection that started at approximately 200 ms, peaked between 300–400 ms, and continued upon the following 700 ms. In the early TW 200–250 ms, the mismatch negativity was present only in anterior cluster, as indicated by the step-down analysis of the Stimulus Type ×

AP interaction (Table 3.5.3). In succeeding TWs between 250–700 ms, ANOVA revealed the main effect of Stimulus Type. The effects of Stimulus Type in anterior-posterior plane were found in the time periods 250–400 ms, 450–500 ms, 650–700 ms, 750–800 ms. The subsequent analyses showed an anterior-central distribution of the mismatch negativity in all the TWs, as well as the presence of effect in the posterior cluster between 300–400 ms. Furthermore, an interaction Stimulus Type × AP × LP was found in TWs 250–300 ms ($F(4, 132) = 2.62$, $p = .038$), 300–350 ms ($F(4, 132) = 2.50$, $p = .046$) and 350–400 ms ($F(4, 132) = 3.85$, $p = .005$). The analysis of these interactions revealed region-specific distribution of Stimulus Type effect in anterior-central areas ($F(1, 33) = 9.83$–26.55, $p = .000012$–$.004$) between 250–400 ms, but also in three posterior regions in TW 300–350 ms ($F(1, 33) = 5.39$–6.94, $p = .013$–$.027$), and posterior-right/posterior-middle regions in TW 350–400 ms ($F(1, 33) = 4.35$–6.20, $p = .018$–$.045$).

Table 3.5.3. Analysis of variance as calculated in Experiment 1d in adults: standard *den* versus deviant *den*.

TW	**Main effect of stimulus type *F*(1, 33)**	**Type × AP (df) F**	**Type × AP Resolved**		
			ANT	**CENT**	**POST**
200–250		(1.34, 44.21) 3.80*	4.68*	-	-
250–300	12.40**	(1.35, 44.51) 9.20**	14.03**	13.02**	-
300–350	18.20**	(1.37, 45.03) 8.73**	18.69**	18.58**	6.78*
350–400	22.90**	(1.35, 44.41) 15.82**	26.47**	22.73**	5.24*
400–450	11.44**				
450–500	10.90**	(1.37, 45.13) 5.39*	12.81**	8.18**	-
500–550	11.56**	(1.24, 40.91) 3.98*	11.91**	9.73**	-
550–600	6.71*				
600–650	12.37**				
650–700	11.67**	(1.53, 50.51) 6.83**	18.34**	8.73**	
750–800	6.15*	(1.40, 46.20) 3.65*	8.83**	4.79*	
850–900	4.75*				

Note. TW, time window; AP, anterior-posterior plane; ANT, anterior; CENT, central; POST, posterior.

Based on these results, the time period between 200–450 ms was chosen for MMN quantification in *den*. The mismatch response to *den* peaked at 343 ms (*SD* = 52 ms) after the onset of the stimulus, that is, 185 ms post-deviance. The mean amplitude of the local peak was -3.06 μV (*SD* = 2.15 μV, see Figure 3.5.3 for a summary of results).

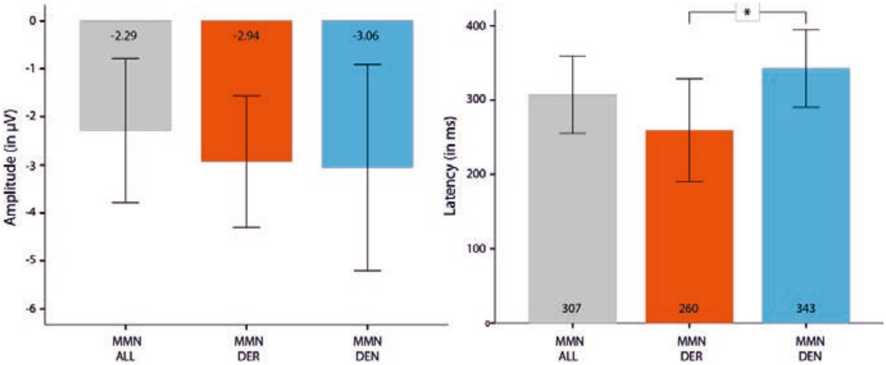

Figure 3.5.3. Mean amplitudes and latencies of the mismatch responses for all articles (in grey), *der* (in red) and *den* (in blue) in adults. Latency values are plotted in relation to stimulus onset. Error bars indicate one standard deviation.

As can be seen in Figure 3.5.3, determiner *den* elicited a greater mismatch response at later latencies than determiner *der*. The paired-sample t-test showed that the MMN to *den* peaked significantly later than MMN to *der* ($t(33) = -6.01$, $p < .001$). However, the amplitudes of two mismatch negativities did not differ ($t(33) = .31$, $p = .752$).

Discussion

In Experiment 1d, the ability of adults to discriminate between naturally spoken articles *der* and *den* in a mismatch paradigm was investigated. The MMN response peaked at 149 ms after the point of deviation, and was distributed in fronto-central areas. This result was in agreement with the studies that explored mismatch negativity to speech contrasts, including isolated (e.g., Jacobsen, Schröger, & Alter, 2004; Rinne et al., 1999), syllable-embedded (e.g., Kraus et al., 1992; Paquette et al., 2013; Shtyrov et al., 2000) and word-embedded sounds (e.g., Pulvermüller et al., 2001; Scharinger et al., 2012).

Separate analyses of the mismatch response to the determiners *der* and *den* revealed two distinct patterns. Both MMN peaks lied within the range previously reported in the literature for MMN in adults (Näätänen et al., 2007). Whereas deviant *der* produced a short-lasting negative deflection with a clearly defined peak at 102 ms post-deviance, MMN to the deviant *den* peaked significantly later at 185 ms after change onset and was followed by a sustained negativity. No amplitude differences were found. That is, the mismatch responses differed in two features: peak latency and presence of the late sustained negativity. The main aspects of the stimulus materials that may have contributed to this asymmetry are discussed in the following.

Although determiners were compared individually in both conditions to reduce the influence of their physical properties on MMN, there is a number of acoustic and articulatory factors that can potentially explain the MMN patterns in the current study. First, the asymmetry may be due to the frequency change of F1–F4 in a sequence standard-deviant, as it was discussed in case of children data (Chapters 3.3 and 3.4). Second, duration of stable vowel [ɛ] may have impact on the MMN patterns for *der* and *den* (Amenedo & Escera, 2000; Colin et al., 2009; Jaramillo, Alku, & Paavilainen, 1999; Peter et al., 2010; Takegata, Tervaniemi, Paavo, Ylinen, & Näätänen, 2008). However, in the latter studies, the increment duration MMN was associated with smaller MMN amplitudes. This result was explained by the processing of change magnitude that in case of duration increment can be processed only at the end of the deviant. In contrast, in case of duration decrement, the magnitude of change can be processed as soon as the deviance is detected. In the current experiment, vowel duration increment was associated with the additional sustained negativity that followed the mismatch response, which contradicts to these findings. Moreover, no latency differences were found for the duration change, when calculated with the ‘same-stimulus’ method, that is, when individual items were presented both as standards and as deviants. Thus, neither latency shift nor additional negativity in *den* may not be attributed to the duration difference of the stable vowel [ɛ].

An alternative explanation of the MMN asymmetry may be found in the word occurrence frequency of the article forms in adult language. Words with a higher frequency of use in specific language were shown to elicit an enhanced ERP response (Alexandrov et al., 2011; Leminen et al., 2013; MacGregor & Shtyrov, 2013; Pulvermüller et al., 2001; Shtyrov et al., 2011). In addition, Alexandrov et al. (2011) observed a latency shift such that the MMN to the high-frequency word peaked approximately 50 ms earlier than the MMN to the low-frequency word. Our data corroborates these findings. Corpus-based analysis (see Section *Materi-*

als in Chapter 3.2) showed that the article form *der* occurs much more frequently in spoken and written adult speech than *den*, independently of their function. Similar to the data of Alexandrov et al. (2011), the high-frequent form *der* elicited an earlier response than the low-frequent form *den* in the current study[9]. These results are also consistent with a number of non-MMN studies on visual word recognition in which common words were processed more rapidly than rare words. Linguistic experience was shown to speed up word processing in sentential context in a study by King and Kutas (1998). Peak latencies of the negativities elicited during prose reading were highly correlated with the word frequency and length, as assessed by regression analysis in a work by Osterhout, Bersick, and McKinnon (1997). M350 was suggested to reflect the word frequency effect in a MEG study, in which lexical decision task was employed (Embick, Hackl, Schaeffer, Kelepir, & Marantz, 2001). Together with the data from Alexandrov et al. (2011) and studies on visual word recognition (e.g., Hauk & Pulvermüller, 2004; Sereno, Brewer, & O'Donnell, 2003) our findings imply that the access to the frequency information is available at an early stage (within 200 ms) of the auditory word processing (Pulvermüller, Shtyrov, & Hauk, 2009).

To summarize, Experiment 1d examined the pre-attentive processing of acoustic change between two naturally-spoken determiners *der* and *den* in adults using an oddball paradigm. As expected, deviants elicited a mismatch negativity indicating their ability for word discrimination within the first 200 ms after the point of physical deviance. Furthermore, the MMN to the deviant *den* peaked significantly later than the MMN to the deviant *der*. These discrepancies were explained by acoustic and lexico-distributional factors. Age-related differences between the groups will be discussed in the next section.

3.6 Age-related differences in mismatch response

In order to examine the maturational pattern of mismatch negativity, two analyses were performed. First, the development of the ability to differentiate between determiners at group level was examined. That is, the mismatch response

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[9] Interestingly, a late sustained negativity for a low-frequency word could be seen in the study by Alexandrov et al. 2011 (see Figure 4, p. 5). However, this negativity was not discussed in detail.

to the deviant was analyzed across three age groups: 2-year-olds, 3-year-olds and adults. In other words, the results of the Experiment 1a were compared to the results of the Experiments 1c and 1d. Due to the differences in experimental design between age groups, cross-sectional comparisons of the MMN amplitude and latency were performed using only two conditions and a matched sample of data. Since the adults' response did not contain late discriminative negativity, full cross-age analysis was conducted on the early negativity. Late negativity was compared only between 2- and 3-year-olds. In order to conduct this analysis, a sample of children who participated in the MMN experiment both at the age of 2 and 3 was selected, that is, the maturation of the late negativity was assessed in within-subject comparison.

Second, the maturational trajectory of the mismatch response to individual articles was examined. This analysis was limited to the age groups of 3-year-olds and adults. A sample of 34 children was chosen for this analysis to match the number of datasets included in grand average for adults. While three-year old children showed a multi-phase negativity to the deviant *der*, their response to *den* contained only late negativity. Adult pattern was different: both *der* and *den* elicited an early classical mismatch negativity, which was followed by a slow negative wave only in *den*.

Based on the previous literature, we hypothesized that

- the amplitude of the mismatch response either does not change or correlates negatively with age both for determiner-independent and determiner-specific analyses (Kraus et al., 1993);
- the MMN peak shifts to earlier latencies as a function of age both for determiner-independent and determiner-specific analyses (Kraus et al., 1993; Kraus et al., 1992; Paquette et al., 2013; Shafer et al., 2010);
- the amplitude of the late mismatch response diminishes with age (Bishop et al., 2011; Kraus et al., 1993).

Data analysis

A sample of 39 children was chosen for the developmental analysis of mismatch negativity. All these children participated in Experiment 1a when they were 2-year-old and in Experiment 1c when they were 3-year-old. In addition, all 34 adults were included (for main characteristics of the age groups, see Table 3.6.1). Since 2-year-old children were each exposed to only one experimental condition (i.e., they either received *der* or *den* as a standard during the experiment), only the corresponding data from 3-year-olds and adults was used for the comparative analysis.

Table 3.6.1. Main characteristics of the participant sample included into comparative analysis of the mismatch response to *der*/*den*.

	Total number	**Mean age (SD)**	**Gender**	**Handedness (SD)**
2-year-old	39	29.72 (3.24) months	22 girls	-
3-year-old	39	41.82 (3.38) months	22 girls	49.62 (42.66)
Adult	34	27.32 (3.70) years	15 female	88.18 (16.43)

Note. Standard deviation is indicated in parentheses.

Analysis of the developmental pattern of the mismatch response to the determiner *der* was conducted on a randomly chosen sample of 34 three-year-old children and all 34 available datasets from adults.

Local MMR peaks were defined automatically using ERPLAB Measurement Tool (Lopez-Calderon & Luck, 2014) within the latency range in which statistically significant differences between stimulus types were observed. That is, in 2-year-old children, the MMN peaks were quantified in time windows 300–500 ms and 500–900 ms (for definition of these time windows, see section *Results* in Chapter 3.3). In 3-year-old children, time windows 350–500 ms and 600–900 ms were used (for definition of these time windows, see section *Results* in Chapter 3.4). In adults, only early negativity between 200–400 ms was explored (for details, see section *Results* in Chapter 3.5). Peak latencies and amplitudes were measured at the electrode site Fz that corresponded to the electrode 11 in the Geodesic Sensor Net.

Statistical analyses were performed using SPSS program, version 22 (SPSS, Inc., Chicago, IL, USA). Cross-age differences were tested by analysis of variance (ANOVA) with age group as a between-subjects factor [2-year-olds; 3-year-olds; adults]. Turkey's post-hoc test was used for further comparisons.

Results of the peak analysis

Figure 3.6.1 presents the difference waves of 39 children at the age of 2 years, the same children at the age of 3 years and 34 adults at the electrode site Fz (E11).

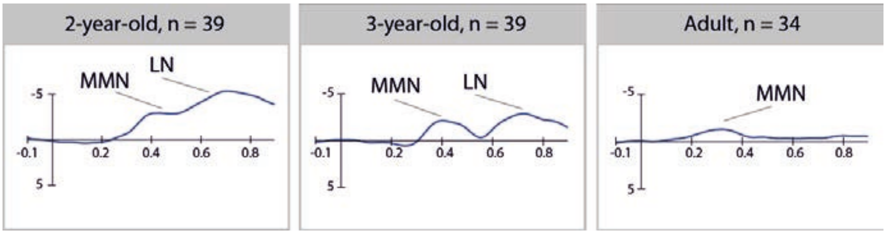


Figure 3.6.1. Deviant-minus-standard deviant waves obtained for the determiners *der*/*den* in three age groups. The ERP represent sample data obtained in Experiment Ia (2-year-old), Experiment Ic (3-year-old) and Experiment Id (adult). MMN, mismatch negativity; LN, late negativity. ERP data has been low-pass filtered at 7 Hz for visualization.

Figure 3.6.2 summarizes the results of latency and amplitude analysis for early and late negativities in three age groups. For the early mismatch negativity, a significant between-group effect for the peak latency was found (F(2, 109) = 52.08, *p* < .001). Post-hoc tests revealed significant differences between adults (310.71 ms, *SD* = 56.81 ms) and 3-year-olds (415.18 ms, *SD* = 44.73 ms), *p* < .001, as well as adults and 2-year-olds (406.46 ms, SD = 42.10), *p* < .001. Latency differences between two young groups were not significant (*p* = .70). The amplitude of the early mismatch response did not change significantly with age (*F*(2, 109) = 1.70, *p* = .19).

The late negativity was analyzed only in children. There were no significant effects for the latency of the late response (*F*(1, 76) = .79, *p* = .38). In 3-year-olds, the amplitude of the late response was significantly smaller (-5.91 µV, *SD* =

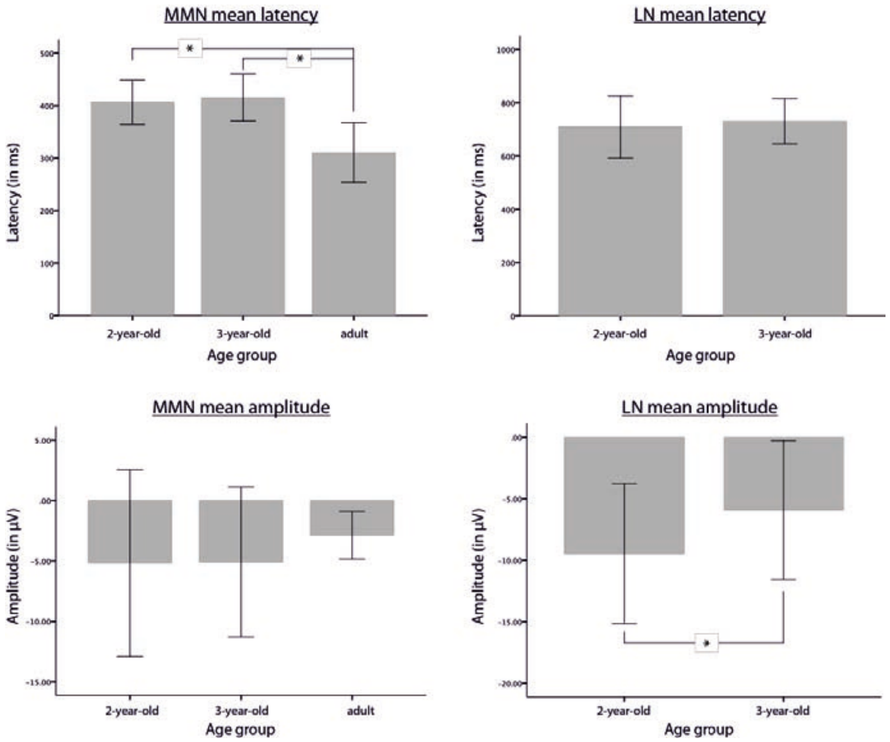


Figure 3.6.2. Mean peak latencies (upper panel) and amplitudes (lower panel) for the early mismatch negativity (left) and late negativity (right), as observed for the deviant *der*/*den* in all age groups. Error bars indicate one standard deviation. MMN, mismatch negativity; LN, late negativity.

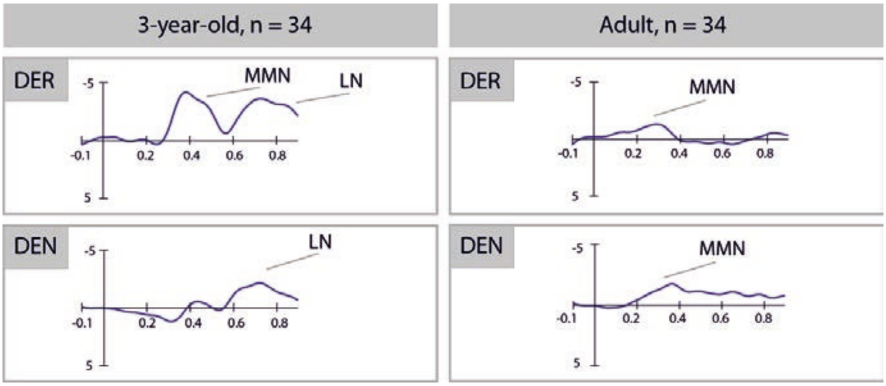


Figure 3.6.3. Deviant-minus-standard deviant waves obtained for the determiners *der* and *den* at the electrode site Fz (E11) in 3-year-olds and adults. MMN, mismatch negativity; LN, late negativity. ERP data has been low-pass filtered at 7 Hz for visualization.

5.65 µV) than in 2-year-olds (-9.47 µV, *SD* = 5.70 µV), as assessed by the one-way ANOVA: *F*(1, 76) = 7.66, *p* = .007).

One-way ANOVA with factors Age and Peak latency was calculated to assess the developmental trajectory of the early mismatch response to the deviant *der*, as compared to the standard *der* (Figure 3.6.3, upper panel).

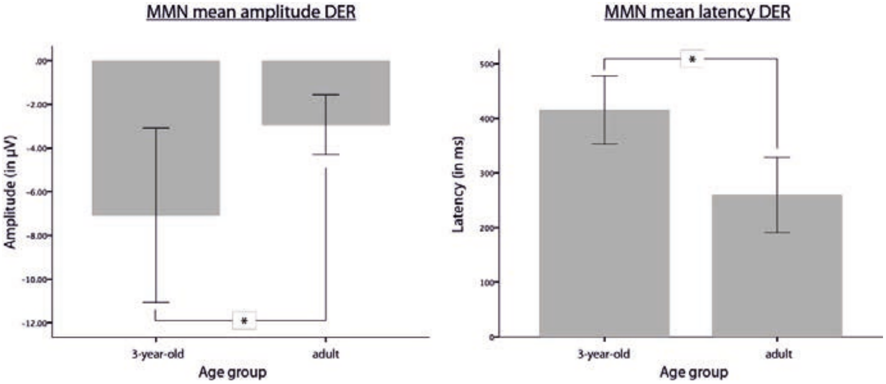


Figure 3.6.4. Mean peak amplitudes (left panel) and latencies (right panel) for the early mismatch negativity, as observed for the deviant *der* in 3-year-olds and adults. Error bars indicate one standard deviation. MMN, mismatch negativity.

This analysis showed that the mismatch response peaked significantly later in 3-year-olds than in adults (*F*(1, 66) = 94.83, *p* < .001). Its amplitude at the electrode site Fz differed significantly between age groups (*F*(1, 66) = 32.69, *p* < .001). The follow-up analyses with two random samples of 3-year-old participants showed the same results: significant differences for latency (*F*(1, 66) = 87.88, *p* < .001; *F*(1, 66) = 86.55, *p* < .001) and amplitude (*F*(1, 66) = 10.46, *p* = .002; *F*(1, 66) = 39.81, *p* < .001).

Discussion

Current analyses aimed to explore age-related differences between mismatch negativity responses 1) to the deviant determiner at group level, and 2) to the specific determiners in within-subject design. The morphology of the mismatch negativity to the deviant determiner at the group level showed a typical developmental pattern. A slow negative wave obtained in 2-year-olds was substituted by a clear peaked activity in 3-year-olds. The multiple peaks associated with children data were not present in adult ERPs. These results are consistent with the developmental trajectory of ERP components and may be explained by reduced synaptic activity in the maturing brain (DeBoer, Scott, & Nelson, 2005).

Age-related comparisons of the mismatch response to the deviant *der*/*den* revealed that the MMN peaks significantly earlier in adults than in 2-year-olds and 3-year-olds. This result agrees with other studies that found MMN latency shifts from a developmental perspective (e.g., Gomot et al., 2000). In line with this tendency, older age groups, for example, 7- to 11-year-old children in a study by Kraus et al. (1993), did not show significant differences for peak latencies, as compared to adults. The earlier mismatch response in adults might be explained by a number of factors, including the low level of scull conductivity, less specific connectivity between cortex parts, later myelinisation of frontal areas and different orientation of MMN generators in children's, as compared to adult's brain (Cheour et al., 2000; DeBoer et al., 2005).

The amplitude of the early mismatch response to the deviant did not change significantly with age. This finding supports a number of studies that found no magnitude differences in cross-sectional comparisons within similar age range (Glass et al., 2008b; Morr et al., 2002). As predicted, the amplitude of the late discriminative response decreased significantly between 2- and 3-year-old children. Together with the adult data, in which the late discriminative response was absent, this result indicates that the late mismatch negativity is less robust than the MMN. This agrees well with findings by Kraus et al. (1993) who observed amplitude reduction for the late discriminative negativity in adults, as compared to 4- to 11-year-old children. Furthermore, in their study with school children, Bishop et al. (2011) showed that the late discriminative negativity was larger for small deviants /ba – da/ than for large deviants /ba – bi/. The late response was argued to reflect additional processing efforts for the stimuli, in which acoustic differences are more difficult to detect. These results, together with the developmental tendency found in the current and other studies, indicate that late discriminative negativity may be modulated by linguistic experience.

The impact of experience in linguistic environment and maturational changes was further explored in determiner-specific analyses. The mismatch negativity to the deviant *der* was present in both 3-year-olds and adults. It peaked significantly earlier and with a smaller amplitude in adults than in children. Thus, the MMN to the deviant *der* displayed a common developmental pattern with a characteristic latency and amplitude reduction. The acoustic processing of the deviant *den* underwent a considerable morphological change across age groups. Deviant *den* did not elicit a significant early mismatch response in 3-year-old children, whereas adults showed a traditional mismatch negativity. On the one hand, long-term natural exposure to the form *den* might explain this transformation (see also Cheour, Shestakova, et al., 2002). On the other hand, the developmental transformation of the MMN to the deviant *den* might be due to the increased sensitivity to the acoustic cues that alternate in the sequence *der*-*den*. The candidate acoustic change was the shift of the frequency of the formants F1–F4. Previous research into sound discrimination in children showed that the auditory thresholds differed between children and adults (Aslin, Clayards, & Bardhan, 2008). For example, using head-turning techniques, Sinnott and Aslin (1985) showed that the difference limens of 7–9 months infants ranged from 11–29 Hz, whereas the adult threshold was 3–5 Hz. Although frequency discrimination improve with age significantly, it remained poorer in 6-year-olds than in adults (Jensen & Neff, 1993). The frequency discrimination threshold correlated negatively with age, as assessed by performance in discrimination task completed by 8- to 11-year-old children and adults (Moore, Ferguson, Halliday, & Riley, 2008). Behavioral studies, thus, revealed an age-related improvement of the main auditory abilities in children, including frequency discrimination. On the other hand, the accuracy of behavioral discrimination was shown to highly correlate with the amplitude of the mismatch negativity (for review, see Näätänen et al., 2007). Taken together, these findings might explain the dramatic change of the MMN pattern to the determiner *den*.

3.7 Conclusion

The present series of the oddball experiments aimed to explore children's and adult's ability to auditorily discriminate between naturally spoken forms of the German definite article. Specifically, we investigated the auditory processing of masculine singular forms *der* and *den* in adults and children at the age of 2–3 years. In sentential contexts, these forms unambiguously indicate thematic relations between the verb arguments. While the masculine singular nominative form *der* is used to express the thematic relation of agency, the masculine singular accusative form *den* assigns the role of patient in German simple transitive sentences.

The ERP component *mismatch negativity* was used as a neurophysiological index of pre-attentive auditory discrimination. The experiments revealed that deviants (*der* or *den*) elicited a mismatch response in both children and adults. The latency and the amplitude of the mismatch negativity were consistent with the previous literature on speech sound discrimination. These findings imply that children at the age of 2 and 3 are able to recognize and acoustically discriminate between two linguistic items, when they are presented in isolation. In other words, *der* and *den* can be *identified* during early childhood.

Furthermore, interesting differences in the MMN patterns to specific determiners were observed in children. While determiner *der* elicited a multi-phase response that included an early mismatch negativity followed by a late negativity, no significant differences between standard and deviant were found in the early mismatch window for *den*. Only a late response was observed for this determiner in children. This situation changed dramatically over age with both determiners eliciting a classical mismatch response in the oldest group.

Two non-exclusive factors were proposed to have impact on within-age asymmetry of the MMN pattern. On the one hand, acoustic changes, that is, frequency shifts, might have triggered the ERP differences between mismatch responses to specific determiners. Although the stimulus material was controlled for the fundamental frequency, intensity and overall duration, the structure of the multiple formant frequencies in speech stimulus and its change in the standard-deviant sequence might explain the MMN effects both in children and adults. Thus, the MMN asymmetry might be due to the different processing of acoustic complexity of the current stimulus material.

On the other hand, the processing of two meaningful speech items was investigated in the current study. Both of them are intensively used in spontaneous and non-spontaneous speech of both adult and children, as it was shown in the corpus-based analysis. However, their frequency distribution displays an asymmetric pattern with much greater occurrence of the form *der* in the linguistic environment than of the form *den*, independently of their functional role. Previously, long-term memory traces were shown to have impact on the MMN in the studies of phonological, but also higher-order language processes, including lexical, semantic and morphosyntactic processing. MMN was also shown to undergo morphological changes due to the natural exposure to non-native contrasts. These studies indicated that the mismatch negativity is modulated by experience in the linguistic environment. In our analysis, exposure to the determiner form *der* appeared to be greater than that to the determiner form *den*. Hence, long-term memory representations of two forms were claimed to contribute to the asymmetry of MMN patterns within all age-groups.

Across-age transformation of the mismatch negativity was consistent with the common findings in developmental MMN and ERP literature. The negative sustained wave in 2-year-olds was substituted by a two-peak negativity in 3-year-olds and a classical MMN peak in adults. These results were explained by the tuning of the auditory system and the improvement of its sensitivity to the acoustic cues of the native language. Following this line, adult-like response to the acoustic change in the current paradigm would be expected in children between 8 and 10 years of age.

The generalizability of these results is subject to certain limitations. First, in our study, the word recognition point was defined by means of acoustic analysis. On the basis of formant behavior and energy changes, it was set to 158 ms. In terms of the cohort word recognition theories, 158 ms is a word uniqueness point, that is, the point to which two words are identical (Frauenfelder & Floccia, 1999; McQueen, 2007). It might not necessarily correspond to the recognition point, that is, the point at which the participants perceive the difference between two words. The recognition point is dependent on contextual factors (e.g., sentential environment) and can be defined by a number of tasks, including gating, word shadowing and other methods (for review, see McQueen, 2007). Previous studies have shown a strong relationship between the recognition and uniqueness point most notably for those lexical items in which the uniqueness point occurred early in the word (Radeau & Morais, 1990). Since the items were presented in an isolated mode in the current experiments, and the range of possible competitors was limited to two, the word recognition point might be located very close to the uniqueness point in our stimuli.

Second, the comparison of two specific forms *der* and *den* might not reflect the whole picture of determiner discrimination in children. The German case system challenges children with less discriminable forms (e.g. *den* [dɛn] and *dem* [dɛm], *ein* [ain], *eine* [aine], *einen* [ainen] and *einem* [ainem]), so that the acquisition of case system is partly obscured by phonetic processing difficulties. Our experiments revealed, however, that the auditory system of 2- and 3-year-old children is mature enough to distinguish between different forms of functional words, when they are presented in an isolated mode.

4 The processing of case marking in sentential context: behavioural study

4.1 Introduction

In the experiments using a mismatch response we investigated the question whether children at the age of 2 and 3 are able to acoustically identify and differentiate between two determiners *der* and *den*. The following experiments seek to explore the ability of preschoolers to use these determiners for interpretation of transitive sentences in a behavioral task.

This chapter is divided in five parts. The first part gives an overview of the acquisition trajectory of the German case system. Developmental aspects of the establishment and use of animate-inanimate distinction are discussed. In the following subsection *Current study*, design of the behavioral experiment is presented. Sections 4.2–4.3 summarize the results of the picture-matching experiments for each age group in detail. In the following section, age-related comparisons are presented. Finally, section 4.5 gives a brief summary of the findings.

The acquisition of case

Diary studies and analyses of spontaneous speech that focused on the acquisition of case by German-acquiring children reported the first case inflections on determiners in the beginning of the third year (Clahsen, 1984; Mills, 1985; Tracy, 1986). Exceptionally early talkers showed their first accusative forms even earlier. For example, the girl Lisa in the study by Czepluch (1996) produced her first accusative forms at the age of 2;1.

Most studies agree on the following order of case acquisition: nominative > accusative > dative > genitive (Clahsen, 1984; Meisel, 1986; Tracy, 1986). Variations in this acquisition sequence are associated with some particular expressions of case. For example, the possessive *–s* form of genitive was reported to be acquired by the girl Simone prior to accusative and dative affixation in the study by Clahsen, Eisenbeiss, and Vainikka (1994). This observation was explained by different morphological realizations of case. While accusative required a carrier, such as determiner, genitive suffix *–s* could be used on already available nouns, e.g., *das is mones boot* 'that is Simone's boot' (Clahsen et al., 1994, p. 97). Moreover, the use of genitive form was limited to proper names and kinship terms that occurred frequently in child-directed input.

Due to the variations in the rate of language acquisition, the developmental sequences in studies on case acquisition have been often described in terms of the mean length of utterance (MLU) that was shown to uniformly reflect constructional and semantic knowledge (Brown, 1973a, 1973b). During the stage I (MLU ≤ 1.75, age 15−30 months) children start to produce their first two-word utterances. Stage II (MLU ≤ 2.25, age 28−36 months) and stage III (MLU ≤ 2.75, age 36−42 months) are characterized by the use of simple syntactic rules and grammatical morphemes. More grammatical morphemes occur during the stage IV (MLU ≤ 3.50, age 40−46 months). Complex sentences appear during the stage V (MLU > 3.50, age 42−52 months) (Brown, 1973b; Clahsen, 1984). Case acquisition sequences were mapped onto the linguistic development in the following way (Clahsen, 1984; Tracy, 1986):

1. No case markers are used during the stages II and III. Noun phrases do not contain determiners, and personal pronouns are not case-marked: *bus fahrn* 'bus ride' (Tracy, 1986, p. 55).
2. During the stage IV, children use case-neutral markings in accusative and dative contexts: *ich bau ein turm mit ein uhr* 'I build a tower with a clock' (Tracy, 1986, p. 55).
3. Case-marked forms appear during the stage V. These include:
    a. accusative marking on definite articles, demonstrative pronouns, pronouns: *papa jetzt den elefant machen* 'Papa now the.ACC elephant make' (Tracy, 1986, p. 57). Accusative forms are used in dative-contexts both for nouns and pronouns: *da kann man mit den auto hinfahr* 'one can go there with the.ACC car' (Clahsen, 1984, p. 11);

b. Dative forms, that start to differ from accusative marking at the end of stage V.

Some discrepancy exists between the use of determiners and MLU levels in the literature. Whereas in the data by Clahsen (1984) no articles were observed during stage II (MLU = 2.75) and nominative forms appeared during stages III-IV, Szagun (2004) found case-marked article forms from MLU of 1.8. She observed frequent case markings when the level of MLU reached 3.5. These results were explained by methodological differences, including the use of twins' data in the study by Clahsen (1984).

In general, the acquisition of case markers has been described as slow in German, as compared to other languages, e.g., Turkish (Mills, 1985; Szagun, 2004; Tracy, 1986). This might be due to several reasons. First, many researchers agree on homonymy as one of the core problems of case acquisition. As mentioned before, there is no one-to-one correspondence between form and function in the system of case markings. For example, the indefinite article *ein* carries both nominative and accusative case functions for neuter nouns. Learning multiple correspondences requires more cognitive effort than learning one-to-one relationships. Second, apart from case, determiners also carry information on gender and number, such that several grammatical functions are fused in one form. Only in a few cases, grammatical case is marked on nouns, e.g., *des Mannes* 'the.GEN man.GEN'. Acquiring merged grammatical categories might be more demanding than one-to-one correspondences between form and function (Tracy, 1986). Yet, analyses of children's spontaneous speech by Bittner (2006) showed that within this grammatical merge, case-related features are acquired earlier than functional features related to gender. Finally, the slow rate of case acquisition might be explained by perceptual differences. Articles are not perceptually salient, because they usually lack stress in the utterance. Furthermore, children might not easily discriminate between some forms of articles, e.g., between *den* [dɛn] and *dem* [dɛm] (Szagun, 2004, but see our data from Experiment I).

Although diary and production studies showed that German-acquiring children produce case-marked forms from the age of three, behavioral experiments with young children indicate the ability to use grammatical markers for sentence interpretation only by the age of five to six years (Dittmar et al., 2008; Knoll et al., 2012; Primus & Lindner, 1994; Schaner-Wolles, 1989; Schipke et al., 2012). For example, in the study by Schaner-Wolles (1989), 3-, 4- and 5-year-old children were presented with object-first (OVS) sentences of types (4.1a)–(4.1b) in sentence-picture matching task with three-picture arrays.

(4.1a) *Den Vater fotografiert der Bub.*
the.ACC father photographs the.NOM boy
'The boy photographs the father.'

(4.1b) *Dem Mädchen setzt der Vater die Haube auf.*
the.DAT girl puts the.NOM father the.ACC cap on
'The father puts the cap on the girl.'

(4.1c) *Den Vater frisiert das Mädchen.*
the.ACC father combs the.NOM(ACC) girl
'The girl combs the father.'

(4.1d) *Das Mädchen zwickt der Bub.*
the.ACC(NOM) girl pinches the.NOM boy
'The boy pinches the girl.'

Data was reported only descriptively in this study. Five-year-olds showed the lowest error rates for accusative-first structures: 5.6% for sentences with unambiguous case marking on the second NP (4.1a), and 16.7% for ambiguous case marking on the second NP (4.1c). Dative-first sentences, as (4.1b), were also correctly interpreted by 5-year-old children (11.1% of errors). Four-year-olds performed at chance level with all OVS sentences. Primus and Lindner (1994) reported very similar results in the study of 4- to 6-year-old children that performed an act-out task with sentences as in (4.2a)–(4.2c) and their nominative-first versions.

(4.2a) *Den Hahn schubst der Frosch.*
the.ACC rooster pushes the.NOM frog
'The frog pushes the rooster.'

(4.2b) *Den Hahn der Frosch schubst.*
the.ACC rooster the.NOM frog pushes
'The frog pushes the rooster.'

(4.2c) *Schubst den Hahn der Frosch.*
pushes the.ACC rooster the.NOM rooster
'The frog pushes the rooster.'

Four-year-olds performed at chance for all types of OVS sentences. Five-year-olds made less mistakes in noun-first versions, whereas six-year-olds were above chance with all three word order versions of OVS sentences.

In the picture-matching task conducted by Knoll et al. (2012) after fMRI scanning, children between 4;8–6;8 years of age performed significantly over chance level in OVS sentences of type (4.2a). Mean accuracy for OVS sentences was not correlated with age, whereas the correlation between mean accuracy for SVO sentences and age was significant. However, in another study, that used the same stimulus materials, 6-year-olds responded correctly only in 55.28% of cases, while 3-year-olds were significantly below chance level (Schipke et al., 2012). These results indicated that 3-year-old children used word order strategy to interpret complex sentences. The first encountered argument was assigned the role of agent independently of the case marking.

Dittmar et al. (2008) presented 2- to 7-year-old children with SVO and OVS sentences with unambiguous case marking (4.3a)–(4.3b), as well as sentences with ambiguous case marking (4.3c). In order to assess the ability to use grammatical cues independently of verb semantics, the study used two novel verbs *wiefen* and *tammen*.

(4.3a) *Der Hund wieft den Löwen*. (prototype condition)
the.NOM is weefing the.ACC lion
'The dog is weefing the lion.'

(4.3b) *Der Hund schubst den Tiger*. (control condition).
the.NOM is pushing the.ACC tiger
'The dog is pushing the tiger.'

(4.3c) *Den Bären wieft der Tiger.* (conflict condition)
the.ACC bear is weefing the.NOM tiger
'The tiger is weefing the bear.'

(4.3d) *Die Katze wieft die Ziege.* (word-order-only condition)
the.NOM/ACC is weefing the.ACC/NOM goat
'The cat is weefing the goat.'

Two- and four-year-old children were tested in act-out and pointing tasks. Neither of these age groups showed above-chance performance for OVS sentences indicating that children have not acquired the use of case marking by the age of 4;10. Two-year-olds performed over chance level for SVO sentences with novel verbs in the pointing task but not for SVO sentences with novel verb in the act-out task. Furthermore, they performed very accurately in simple SVO sentences with familiar verbs (75%). In contrast, the accuracy of choice in 7;3-year-old children was 69% for OVS sentences in the pointing task. Although 7;3-year-olds performed significantly better than younger groups in the study by Dittmar et al. (2008), their results show that the acquisition of case marking is not completed by the age of seven. In fact, children between the age of 8 and 14 still produced more errors in perception and production tasks than adolescents (14- to 17-year-olds) and adults in a recent study by Lidzba, Konietzko, Schwilling, Krageloh-Mann, and Winkler (2013).

Taken together, the findings of the studies on the acquisition of case marking in German show that children start to use this cue at the age of 5–6 years, as indicated by the overt behavioral response. Younger children rather rely on other cues, including animacy and word order, when interpreting transitive sentence.

Animate-inanimate distinction in developmental perspective

The ability to differentiate between animate and inanimate entities is a fundamental cognitive process (Keil, 1979; Rakison & Poulin-Dubois, 2001). Numerous behavioral studies showed that the animate-inanimate distinction emerges within the first year of life with some sensitivity present in the first hours and days after the birth (for reviews, see Opfer & Gelman, 2010; Rakison & Poulin-Dubois, 2001). The differentiation between human beings and artifacts, such as musical mobile, toy monkey, manikin or doll, was reported by 12 weeks of age, as measured by looking time and heart-rate level (e.g., Field, 1979). For example, Legerstee, Pomerleau, Malcuit, and Feider (1987) crossed the human-object perception with familiarity and social activity in a longitudinal study with 3- to 25-week-old children. The analysis of looking, smiling, vocalization and reaching showed that infants discriminated between a person and a doll by the age of 5 to 9 weeks.

By preschool age, children are able to make a clear-cut distinction between animate and inanimate entities, although it still undergoes some refinement. In one of a few studies with preschool children, the analysis of verbal explanations produced by 2;6- to 5-year-olds in naturalistic environment showed that they clearly differentiate between living and non-living categories (Hickling & Wellman, 2001). This tendency was reflected by a limited use of biological explanations (as referring to nutrition, growth, illness, reproduction) in relation to inanimate physical objects.

Further research focused on the question as to what attributes children attend to when discriminating between animate and inanimate entities. Opfer and Gelman (2010) differentiated between static and dynamic aspects. Static features included the presence of face, eyes, or legs (Rakison & Butterworth 98); smooth versus angular contours and texture. Dynamic cues are related to a number of features, including the type of motion (self-generated versus other-generated), particular patterns of motion (biological versus non-biological), purpose of action (goal-directed versus aimless, smooth trajectory versus irregular trajectory), contingency of behavior, form of motion (from contact versus at distance), and influence of mental state (intentional versus accidental) (Opfer & Gelman, 2010; Rakison & Poulin-Dubois, 2001). In addition, the type of causal role (i.e., whether the participant was agent or patient in an event) was also investigated in relation to animate-inanimate distinction. Although children seem to be able to differentiate between agent and patient roles in a simple event at the age of 14 months (Cohen, Amsel, Redford, & Casasola, 1998), it is not clear whether they differentiate between animates and inanimates on the basis of this distinction. For example, children between the ages of 15 and 18 months in the study by Golinkoff and Kerr (1978) watched films, in which actor-patient role reversals were crossed with animacy of the participants (man and chair). Infants detected role reversals regardless of changes in the direction of action, as reflected by increasing heart rates. However, no differences were found between reversals in man-man event and reversals in man-chair event.

The impact of animate-inanimate distinction on language development in early childhood was shown in research on the processing of simple syntactic structures (Childers & Echols, 2004; Corrigan, 1988; Corrigan & Odyaweis, 1985; Koff, Kramer, & Fowles, 1980; Lempert, 1989, 1990). In the study by Koff et al. (1980), the animacy of subject/object was crossed with event probability and sentence voice. The authors tested 3- to 5-year old children in an act-out task and found two main effects. On the one hand, probable sentences, such as *The girl pushes the table.*, were easier to understand than improbable sentences, such as *The boy eats the TV*. On the other hand, reversible sentences that contained either animate subject and object (*The brown cow jumps on the white cow.*) or inanimate subject and object (*The nail hits the hammer.*) were more difficult to understand than non-reversible sentences (*The girl pushes the table.*). These results indicated that the animacy cue was attended by children during sentence comprehension.

Animacy was also shown to constrain the acquisition of English passive sentences in 2;6- to 5;3-year old children (Lempert, 1989). In this study, children were taught passive sentences in two conditions: with animate patient (A-patient), as in (4.4a), and with static inanimate patient (SI-patient), as in (4.4b).

(4.4a) *The baby is being touched by the frog.* (A-patient)

(4.4b) *The drum is being touched by the frog.* (SI-patient)

In the training phase, children in the A-patient condition were more productive with passives. In the post-training phase, these children were more likely to use passive for animate patients than children in SI-condition. SI-condition children used passives with animate and inanimate patients equally. The author assumed that animacy was included in the children's "concept" of subject.

Animate actor was shown to be part of the prototypical event scheme for English-acquiring 2- and 4-year-old children in token-placement experiments by Corrigan and Odyaweis (1985) and Corrigan (1988). The authors trained children to place tokens of different colors on the actors and patients in pictures showing four types of sentences. In these sentences, the animacy of agent and patient were manipulated yielding animate-animate, animate-inanimate, inanimate-animate and inanimate-inanimate conditions. Children performed better in sentences with animate Actors than in sentences with inanimate Actors. Furthermore, sentences with animate agent and animate patient were suggested to be more prototypical than sentences with an animate agent and an inanimate patient, although it depended on the verb (Corrigan, 1988).

In a more recent study on learning unfamiliar nouns, Childers and Echols (2004) manipulated the animacy status and labeling syntax in an experiment with 2;6-year-old children. In four event conditions (animate-animate, inanimate-inanimate, animate-inanimate, inanimate-animate) two novel creatures/machines were acting as agents and patients. Events were labeled as *The danu is touching it.* and *It is touching danu.* in agent and patient sentence conditions, respectively. Learning effect was tested by asking the child to point to the *danu*. For the majority of events, children expected novel nouns to refer to animate entities. This tendency was not observed in the patient sentence condition, indicating that children also attended to the positional cue.

The contribution of syntactic and semantic cues in German was further examined in the study by Lindner (2003) that investigated the role of animacy, word order, case marking and agreement in 2- to 9-year-old children and adults. Animacy was the most important factor for sentence interpretation in 2-year-olds and 3-year-olds. Individual analyses showed that among 12 two-year-olds, five children relied only on animacy, another five favored word order, and two switched depending on the sentence construction. Among 12 three-year-olds, four children used animacy. In another eight children, the preference depended on whether animacy was in coalition with other cues. If animacy did not conflict with word order and case marking at the NP, children chose this NP for acting. If there was a conflict between animacy, word order and case marking, children tended to choose the animate NP. Hence, these findings showed that animacy was still important in 3-year-olds' sentence interpretation. By contrast, case marking and agreement were the crucial cues for sentence interpretation in adults.

Chan et al. (2009) compared the use of animacy and word order in German-, Cantonese- and English-speaking children of 2;6, 3;6 and 4;6 years of age. Participants were presented with three types of sentences containing a novel verb and ambiguous case marking on the noun (4.5a)–(4.5c) (here the German and English versions of the stimuli).

(4.5a) *Das Pferd tammt das Telephon.* (animate-inanimate)
the.NOM/ACC horse tams the.NOM/ACC telephone
'The horse tams the telephone.'

(4.5b) *Das Geschenk tammt das Huhn.* (inanimate-animate)
the.NOM/ACC present tams the.NOM/ACC chicken
'The present tams the chicken.'

(4.5c) *Die Kuh wieft die Giraffe.* (animate-animate)
the.NOM/ACC cow meeks the.NOM/ACC giraffe
'The cow meeks the giraffe.'

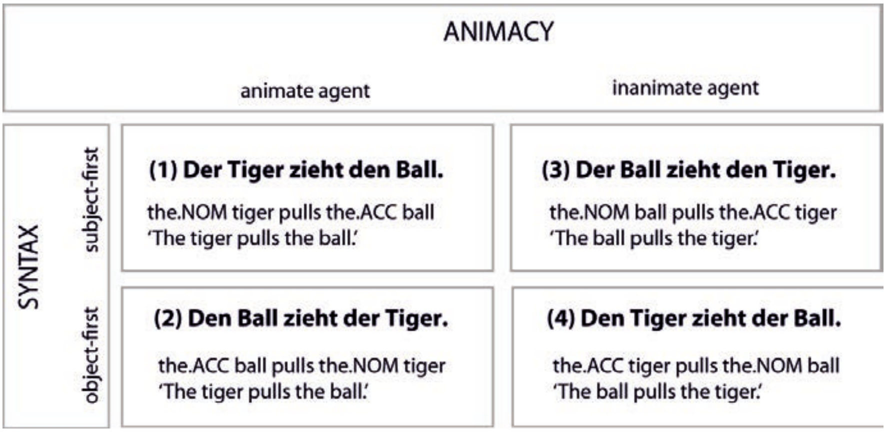
An act-out task was conducted, in which the percentage of peaking the first noun as agent was calculated. When animacy and word order were in coalition, as in (4.5a), German children of all age groups performed over chance level. When animacy and word order were in conflict, as in (4.5b), the youngest group showed no systematic behavior, whereas 3;6- and 4;6-year-olds performed over chance level. In the animacy-neutralized condition (4.5c), German 2;6-year-old children chose the first noun to be the agent significantly more often than by chance. The split-half analysis showed that the older half of 2;6-year-olds performed above chance, whereas the younger half was at chance in this condition. As indicated by significant differences in performance between animate-animate and inanimate-animate conditions, 2;6-year-olds were sensitive to the animacy of the first noun. Such differences were only marginally significant for 3;6-year-olds and not present in 4;6-year-olds. These findings indicated that the role of animacy turned to be less important with increasing age. According to the authors, this phenomenon does not reflect the decrease of sensitivity to the changes in animacy contrast but rather the increasing role of other cues such as case marking.

Corroborating results were reported by Kempe and MacWhinney (1999) who contrasted the use of animacy and case marking in Russian and German adults in a speeded picture-choice experiment. German speakers were more likely to interpret initial animates as agents in sentences with ambiguously case-marked arguments. This tendency was, however, easily overridden by case marking. The decisions were also less influenced by the animacy status of the second noun phrase than by the first noun phrase in their experiment. Similarly, the role of animacy was examined in adults by MacWhinney et al. (1984) along with such cues as word order, agreement, stress in German, Italian and English. Their experiments showed that all the languages had a preference for the animate agent, but it was stronger in German than in Italian and English. For German, the strength of the cues for sentence interpretation was ranked as follows: animacy > agreement > word order (MacWhinney et al., 1984, p. 142).

In sum, studies that manipulated the animacy status of a noun showed that young children are sensitive to the animacy contrasts in sentence. The semantic feature ‘animate’ seems to be included in their concept of agent/subject. Sensitivity to the cue of animacy appears to decrease with age paving the way for morphosyntactic features in sentence interpretation.

Current study

The current experiments intended to examine the processing of morphosyntactic and semantic cues in transitive sentences using a picture-matching task. Two- and three-year-old children were presented with 60 sentences of type [NP – Verb – NP]. Two thirds of these sentences were constructed to assess the contribution of morphosyntactic and semantic cues in children’s sentence interpretation (Figure 4.1.1). Two factors were manipulated in a two-by-two design, namely Syntax (subject-first versus object-first) and the Animacy of the agent/patient (animate versus inanimate). Thematic roles were unambiguously marked by case form of the determiner. In SVO sentences, the first NP was marked by nominative *der*, and the second NP was marked by accusative *den*, as in (1) and (3). In OVS sentences, the first NP was marked by accusative *den* and the second NP was marked by nominative *der*, as in (2) and (4). Furthermore, in one half of sentences the agent was animate and the patient was inanimate, as in (1) and (2). In the other half of sentences, the animacy was reversed, that is, the agent was inanimate and the patient was animate, as in (3) and (4).



		ANIMACY	
		animate agent	inanimate agent
SYNTAX	subject-first	**(1) Der Tiger zieht den Ball.** the.NOM tiger pulls the.ACC ball 'The tiger pulls the ball.'	**(3) Der Ball zieht den Tiger.** the.NOM ball pulls the.ACC tiger 'The ball pulls the tiger.'
	object-first	**(2) Den Ball zieht der Tiger.** the.ACC ball pulls the.NOM tiger 'The tiger pulls the ball.'	**(4) Den Tiger zieht der Ball.** the.ACC tiger pulls the.NOM ball 'The ball pulls the tiger.'

Figure 4.1.1. Syntactic-semantic manipulation in the behavioral picture-matching task.

In the remaining sentences, the semantic cue was neutralized, that is, both arguments were animate nouns (Figure 4.1.2). Thematic roles were expressed by an unambiguous case marking. In subject-first condition, the agent was expressed by the first noun phrase, as in (1). In object-first condition, the agent was the second noun phrase, as in (2).

SYNTAX	subject-first	**(1) Der Tiger schiebt den Hund.** the.NOM tiger pulls the.ACC dog 'The tiger pulls the dog.'
	object-first	**(2) Den Hund beißt der Tiger.** the.ACC dog pulls the.NOM tiger 'The tiger pulls the dog.'

Figure 4.1.2. Syntactic manipulation in the behavioral picture-matching task.

4.2 Experiment 2a: 2-year-olds

Previous studies have shown that children at the age of two have not yet acquired the functional meaning of accusative case marking for interpretation of complex sentences. In terms of the Competition model, the use of the highly reliable cue was not observed at this age. Experiment 2a aimed at replicating these behavioral findings. We hypothesized that 2-year-olds would attend to other cues than case marking during sentence interpretation. Specifically, children were expected to focus on the cue of high availability, that is, on the property of animate noun to be an agent of the sentence. Moreover, children were expected to perform well in sentences with multiple cooperating cues of animacy, case and word order pointing to one interpretation. Thus, we hypothesized that in a purely syntactic contrast two-year-old children will perform

- with near-chance accuracy (Dittmar et al., 2008) or significantly under chance level (Schipke et al., 2012) in OVS sentences;
- over chance level in SVO sentences indicating their ability to understand prototypical sentences with animate agent (Chan et al., 2009; Dittmar et al., 2008).

In sentences with the manipulated agent animacy, 2-year-old children were expected to perform

- over chance level in SVO sentences with animate agent, that is, in sentences with multiple cooperating cues (Chan et al., 2009; Lindner, 2003);
- better in conditions with animate agent than in conditions with inanimate agent due to the use of the animacy cue (Chan et al., 2009; Lindner, 2003);
- over chance level in object-first sentences with congruent animacy contrast (animate agent/inanimate patient) due to facilitation of sentence comprehension by lexico-semantic cues (Lindner, 2003).

Methods

Participants

The behavioral task was conducted with 89 two-year-old children. The data of 27 two-year-olds was excluded from the analysis due to various reasons. Five participants had a hearing/neurological disease history, and one was raised in a bilingual environment. The data of several children were excluded due to the missing (four children) and below-norm performance (10 children) in language development tests and questionnaires (for details, see below). If not motivated to complete the pointing task, children were asked to stick a sticker on the picture of their choice (for details, see *Procedure*). However, participants who completed the task either completely by sticking (14 children) or both by pointing and sticking (nine children) were excluded from the current analysis. Three children were not motivated to complete the task at all. Furthermore, nine 2-year-olds showed a one-side bias in their pointing behavior, that is, pointed at one side in more than 80% of trials. The mean accuracy of performance in the entire experiment lied within 1.5 standard deviations. The final analysis was conducted with the data of 34 two-year-old children (age range 24–35 months, M_{age} = 29.56 months, *SD* = 3.1 months, 19 girls). Low retention rates are explained by high attention and cognitive demands that were necessary to complete the task, as well as by the strict criteria of data inclusion.

Children's language development was assessed using a series of questionnaires and tests. In a separate session, we conducted the *Test zum Satzverstehen von Kindern* (TSVK; Siegmüller, Kauschke, van Minnen, & Bittner, 2010). Two-year-olds received the first subtest of TSVK, in which the comprehension of verb-argument structures was evaluated. All children performed above norm level in the TSVK. One child was excluded, however, due to the missing TSVK data (Table 4.2.1).

Table 4.2.1. Results of the language development diagnostics in the final data sample in Experiment 2a.

Test	**Raw score (n = 34)**			**Normed score (n = 34)**		
	Mean	Range	SD	Mean	Range	SD
TSVK argument structure	6.56	2–10	1.85	60.82	41–76	8.24
FRAKIS vocabulary	82.29	26–107	21.02	65.06	18–96	26.45
FRAKIS word forms	42.53	2–71	16.73	64.10	18–96	27.01
FRAKIS sentence complexity	20.18	2–32	8.84	54.76	18–96	25.33

Note. TSVK, Test zum Satzverstehen von Kindern (Siegmüller et al., 2010). FRAKIS, Fragebogen zur frühkindlichen Sprachentwicklung (Szagun et al., 2009).

Furthermore, parents completed the vocabulary and grammar subcomponents of the *Fragebogen zur frühkindlichen Sprachentwicklung* (FRAKIS), a German version of the MacArthur Communicative Development Inventories (Szagun, Stumper, & Schramm, 2009). The FRAKIS included questionnaires on vocabulary, inflectional morphology and sentence complexity. Parents were asked to fill out the questionnaire at home. Behavioral data of 10 children that were below the norm (percentile ≤ 11) in any of FRAKIS subtests were excluded from the analysis. The results of FRAKIS are presented in Table 4.2.1.

Materials

The use of syntactic and semantic cues for sentence interpretation was examined in a picture-matching task. Sixty sentences of type [NP – V – NP] were constructed (for the full list of sentences, see Appendix A). Each animal/object appeared equally often as agent and patient. Lexical material was chosen upon consulting standard language test SETK-2 (H. Grimm, Aktas, & Frevert, 2000), CHILDES corpus (MacWhinney, 2000) and previous studies on language processing in preschool children (Mahlstedt, 2008; Schipke, 2012). Six verbs were used in sentence material: *schieben* ‘to push’, *ziehen* ‘to pull’, *werfen* ‘to throw’, *beißen* ‘to bite’, *treten* ‘to kick’, and *hauen* ‘to hit’. The actions were carried out by six animate (*der Hund* ‘the dog’, *der Esel* ‘the donkey’, *der Vogel* ‘the bird’, *der Fuchs* ‘the fox, *der Igel* ‘the hedgehog’, *der Tiger* ‘the tiger’), and six inanimate nouns (*der Keks* ‘the biscuit’, *der Kuchen* ‘the cake’, *der Schrank* ‘the wardrobe’, *der Topf* ‘the pot’, *der Turm* ‘the tower’).

A couple of cartoon pictures were created for each individual sentence using Adobe Illustrator (Adobe Systems, Mountain View, CA, USA). Each item contained two scenes that were aligned horizontally on a sheet of paper with the size of 210×297 mm. One scene corresponded to the stimulus sentence. In the other scene, the thematic roles were reversed. The images of all animals and objects were kept in the same size and in the same position within the picture frame. Figure 4.2.1 provides an example of stimulus item for the sentence *Der Vogel wirft den Igel.* ‘The.NOM bird throws the.ACC hedgehog’. Stimulus sentence correctly describes the scene at the right side of the page.

Two lists of 30 sentences, each consisting of five blocks, were compiled. Each block contained items of six conditions: subject-first with neutralized animacy, subject-first with animate agent, subject-first with inanimate agent, object-first with neutralized animacy, object-first with animate agent, object-first with inanimate agent. Two additional versions of the experimental material were designed by reversing the order of these lists. Thus, stimulus material included four lists that were randomly assigned to the children, so that each list could be tested with the equal number of participants.

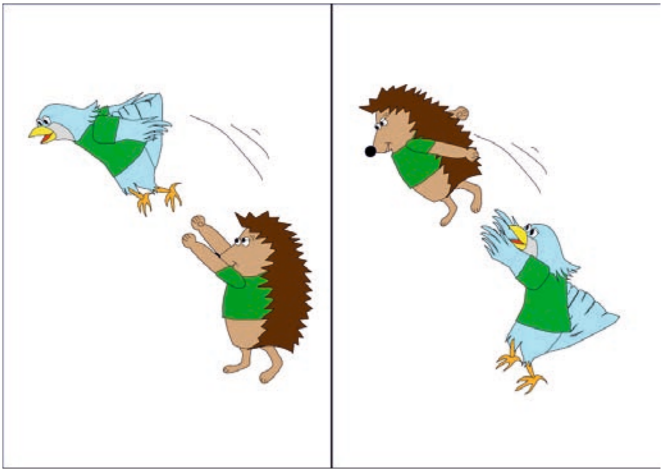


Figure 4.2.1. Example of the stimulus item for the picture-matching task. The stimulus sentence was *Der Vogel wirft den Igel.* 'The.NOM bird throws the hedgehog.ACC'. The target picture is at the right side. The picture with reversed thematic roles is to the left.

The items were pseudorandomized and counterbalanced manually. Identical verbs were not allowed in two consequent trials. Syntactic or semantic structure could not repeat in more than two consecutive trials. In pictures, the target side (left versus right) was counterbalanced within the list. It could repeat at maximum three times in consecutive trials, that is, the response sequences such as left-left-left-left or right-right-right-right were not available. Direction of action was counterbalanced within the list, that is, the agent was to the left of the patient in one half of the pictures, whereas in the other half, the agent was to the right side of the patient.

The experimental material was recorded by a trained female speaker in a child-directed manner. The offline editing included inserting a 50-ms silence period at the beginning and the end of each sentence as well as RMS normalization of amplitude using MATLAB (for detailed acoustic analyses, see Appendix C).

Procedure

The behavioral task was conducted after the EEG experiment, in which the online processing of syntactic and semantic cues was examined. Stimulus material of the EEG experiment contained the same nouns as the behavioral task. Prior to the EEG experiment, children were familiarized with animals and objects in a game-like manner. Participants were presented with the images of animals/objects one at a time and asked to name them. In case the response was correct, the experimenter just repeated the name of the animal/object. In case the child recognized the object/animal but used some other word (e.g., an onomatopoeia *wauwau* ‘bow-wow’ for a dog), the experimenter agreed but corrected the word, repeating the target *der Hund* ‘the dog’ several times. In case the child did not respond, the experimenter just repeated the word several times while pointing to the picture.

Typically, a short break was taken after the EEG experiment. The EEG cap was removed from the child’s head. For the behavioural experiment, that followed, participants were again seated on their parents’ lap in the EEG cabin. Experimenter was seated next to the child to the left or to the right side, as assigned randomly by the experiment assistant. A small table with the picture book was placed in front of the participant so that the child was able to see the entire page. No toys or revulsive objects were allowed in the cabin during the experiment.

First, the task was introduced to the child. The experimenter explained that she and the child were going to play a game. In this game, the experimenter was going to tell short stories to the child. The child was asked to point to the picture that corresponded to the story: “We are going to look at pictures now. I will tell you a short story. Point to the picture that fits the story best!”. Two training items were used to ensure the child understands the task. The training items were: *Der Junge läuft.* ‘The boy is running’ and *Das Pferd isst den Apfel.* ‘The horse is eating the apple’. Training trials did not contain lexical items that were used in the testing phase.

After the training, the experimenter said: “Now, the aunty from the boxes [pointing to loudspeakers] will tell a new story. Point to the picture that fits the story!”. The child was encouraged to listen to the sentence “Now listen to the aunty…” and then point to the picture “Show me!”. In case the child was distracted during stimulus presentation, the sentence was repeated. Parents were solicited for motivational assistance if necessary. However, they were instructed to retain from repeating sentences and giving feedback during the whole experiment.

If children were not motivated to play the game, they were offered to stick small colourful stickers instead of pointing. In this case, the experimenter returned to the training items and explained the procedure. Specifically, the child was encouraged to listen to the sentence and then stick the sticker to the corresponding picture. However, individual participants, who’s data was obtained either entirely or partially by sticking, were excluded from the final evaluation.

Stimuli were presented aurally using Presentation® (Neurobehavioral Systems, Inc, Albany, CA, USA) with the average intensity of 50 dB via Bowers & Wilkins loudspeakers (B&W Group Germany GmbH, Halle, Germany). Loudspeakers were located at approximately 140 cm in front of the participants. Stimulus presentation was prompted by the experimenter by pressing a hidden button. Pointing task had no time limitations. Most children made their choice quite quickly.

Data analysis

Matching picture choice was counted as a correct response. Only unambiguous responses were scored. In case the child pointed at both pictures, or did not listen to the story attentively, or did not look at the pictures, the answer was considered as a miss. For these reasons, 25 of 340 trials were excluded in syntactic manipulation and 43 of 680 trials were excluded in syntactic-semantic manipulation (for details, see Table 4.2.2).

Misses were excluded from the calculation of the performance accuracy. The accuracy score for a specific condition was calculated by dividing the number of correct answers by the number of trials in which an unambiguous response was given: $\frac{Ncorrect}{5-Nmiss} * 100$.

Table 4.2.2. Retention rates for the behavioral experiment with 2-year-olds.

Contrast	**Condition**	**Number of excluded trials**	**Number of retained trials**
Syntactic	Subject-first	14 (8.24 %)	156
	Object-first	11 (6.47 %)	159
Syntactic-semantic	Subject-first animate agent	8 (4.71 %)	162
	Subject-first inanimate agent	9 (5.29 %)	161
	Object-first animate agent	14 (8.24 %)	156
	Object-first inanimate agent	12 (7.59 %)	158

Note. Proportions are indicated in parentheses.

Accuracy data was analyzed in relation to the chance level (50%) using a one-sample t-test. Statistical comparison of accuracy scores for purely syntactic comparison was performed by repeated measures ANOVA with factor Syntax [subject-first; object-first]. The accuracy of response in syntactic-semantic manipulation was statistically evaluated using two-way repeated measures analysis of variance with factors Syntax [subject-first; object-first] and Agent Animacy [animate; inanimate].

The age range of previous studies (e.g., Chan et al., 2009; Dittmar et al., 2008; Schipke et al., 2012) was limited to several months or weeks. The sample of the current study was characterized by a wide age range of approximately one year. To allow for reliable comparisons, two additional analyses were conducted with the present data. First, a Pearson's product-moment correlation was run to determine the relationship between children's performance in picture-matching task and age. Second, based on the results of this analysis, the group was split into two subgroups of similar size. Accuracy of performance was analyzed separately in each group using one-sample t-test and ANOVA.

Results

Syntactic contrast

As can be seen in Figure 4.2.2, there were no differences between 2-year-olds' performance in SVO and OVS sentences ($F(1, 32) < .001$, $p = .988$). They performed at chance level (50%) in both SVO ($t(33) = .65$, $p = .522$), and OVS ($t(33) = .62$, $p = .537$) conditions.

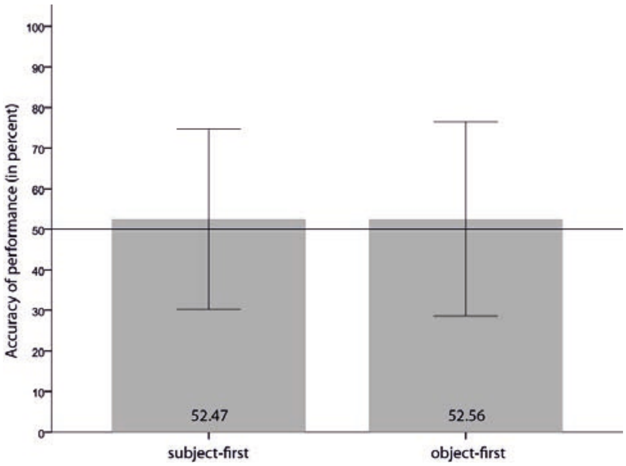


Figure 4.2.2. Mean accuracy of performance in picture-matching task by 2-year-old children in subject-first and object-first conditions with neutralized animacy. Error bars indicate one standard deviation (SD).

No significant correlations were found between children's age and performance in SVO (*r* = -.15, *p* = .431) and OVS (*r* = -.18, *p* = .313) conditions. No significant differences in performance between girls and boys were observed, as assessed by ANOVA with between-subject factor Gender (Syntax × Gender: *F*(1, 31) = .22, *p* = .640). The accuracy of performance was not correlated with FRAKIS score on vocabulary (SVO: *r* = -.08, *p* = .649, OVS: *r* < .001, *p* = 1), on morphology (SVO: *r* = -.10, *p* = .564, OVS: *r* = -.03, *p* = .853), on syntax complexity (SVO: *r* = -.24, *p* = .166, OVS: *r* = .06, *p* = .724).

Syntactic-semantic contrast

ANOVA with factors Syntax (2) and Agent Animacy (2) revealed that 2-year-old children performed significantly better in SVO than in OVS sentences (*F*(1, 33) = 8.93, *p* = .005). No effect of Agent Animacy was found (*F*(1, 33) = 1.37, *p* = .251). The interaction between factors Syntax and Agent Animacy was not significant (*F*(1, 33) = .76, *p* = .387).

Performance in the conditions with animacy contrasts was marginally above chance level for SVO sentences with animate agent (*t*(33) = 2.00, *p* =.050), and near chance level of 50% in all other conditions (Figure 4.2.3; SVO with inanimate agent: *t*(33) = 1.63, *p* = .113; OVS with animate agent: *t*(33) = .67, *p* = .509, OVS with inanimate agent: *t*(33) = -1.75, *p* = .089).

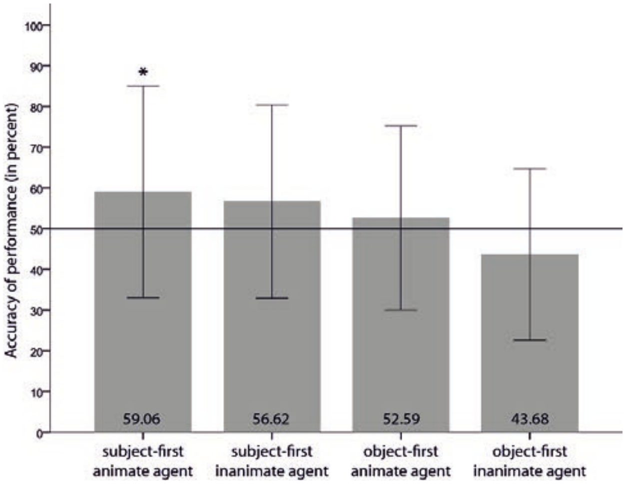


Figure 4.2.3. Mean accuracy of performance in picture-matching task by 2-year-old children in subject-first and object-first conditions with animacy contrast. Error bars indicate one standard deviation (*SD*). Asterisk indicates over-chance level performance, as assessed by one-sample t-test, $p = .05$.

Age was correlated with the accuracy of performance in SVO sentences with animate agent ($r = .66$, $p < .001$) and in OVS sentences with animate agent (r = .36, $p = .038$, Figure 4.2.4). Correlations between age and accuracy in other conditions were not significant (SVO inanimate agent: $r = .02$, $p = .919$; OVS inanimate agent: $r = -.17$, $p = .325$).

Significant correlations between age and performance in picture-matching task were examined in detail. Using median-split analysis two age groups were defined: 24–29 months ($n = 15$) and 30–35 months ($n = 15$). The data of four 30-month-old children distributed close to the median, was excluded from this analysis. The mixed factorial analysis of variance with factors Syntax (2), Agent Animacy (2) and between-subject factor Age (2) revealed the main effect of Age ($F(1, 28) = 8.31$, $p = .007$) and significant interaction Agent Animacy × Age: $F(1, 24) = 4.99$, $p = .034$). There was also the main effect of Syntax: $F(1, 28) = 9.96$, $p = .004$. Separate ANOVAs did not reveal significant effects in the younger group. There were two main effects in the older group: Syntax ($F(1, 14) = 16.22$, $p = .001$) and Agent Animacy ($F(1, 14) = 4.95$, $p = .043$).

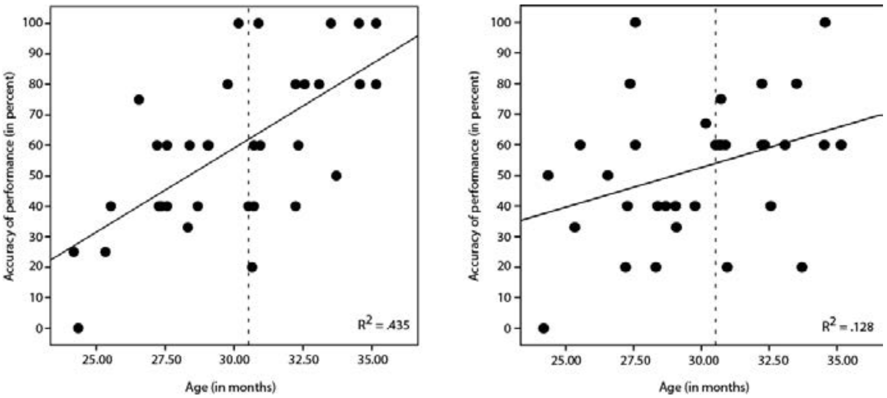


Figure 4.2.4. Relationship between age and performance in subject-first sentences with animate agent (left panel) and performance in object-first sentences with animate agent (right panel). Vertical dashed line represents the median (30.52 months).

One-sample t-tests were conducted to compare the performance of two age groups to the chance level of 50%. No significant results were found for the younger group. In the older group, the accuracy of response to SVO sentences with animate agent/inanimate patient was over chance level ($t(14) = 4.36$, $p = .001$, Figure 4.2.5). The accuracy of response to OVS structures with animate agent was at chance level in this group ($t(14) = 1.77$, $p = .098$).

In the previous studies that investigated the processing of case marking by small children (Dittmar et al., 2008), 2;6- to 2;8-year-olds showed a systematically correct pointing behaviour in sentences of type *Der Hund wieft den Löwen*. 'The dog.NOM is weefing the.ACC lion'. Based on these findings, the performance of our participants in conditions without animacy contrast was reanalysed using the age groups that were defined in the current section. However, none of the age groups showed above-chance behaviour in either SVO (younger 2-year-olds: 59.80%, $t(14) = 1.75$, $p = .102$; older 2-year-olds: 57.33%, $t(14) = 1.23$, $p = .238$), or OVS conditions (younger 2-year-olds: 49.80%, $t(14) = -.04$, $p = .970$; older 2-year-olds: 49.33%, $t(14) = -.11$, $p = .915$).

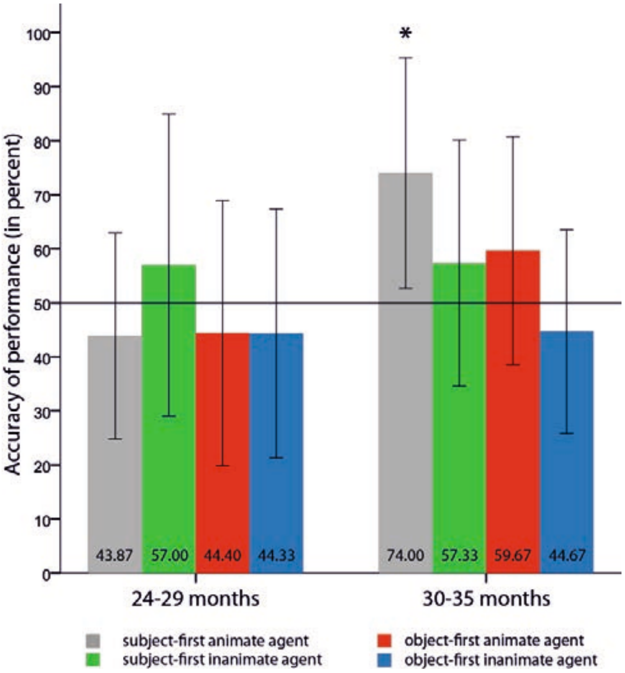


Figure 4.2.5. Mean accuracy of performance in picture-matching task by younger (left panel) and older (right panel) 2-year-olds in subject-first and object-first conditions with animacy contrast. Asterisk indicates over-chance level performance, as assessed by one-sample t-test, $p < .05$.

Dynamics of performance

While studies employing the picture-matching paradigm used a few testing items to evaluate children's behavioral response to various syntactic structures (Boeg Thomsen & Poulsen, 2015; Dittmar et al., 2008, 2011), the current experiment contained 30 critical trials. The following analyses assessed the dynamics of children's performance during experimental session.

First, the pointing behavior across experimental blocks was analyzed. Figure 4.2.6 (left panel) summarizes the accuracy of 2-year-old children in six conditions. Performance in semantically neutral conditions was examined using ANOVA with factors Syntax (2) and Block (5). It revealed a significant interaction Syntax × Block: $F(4, 88) = 3.44$, $p = .012$. Step-down analysis of differences between response to SVO and OVS sentences showed that they were significant in block 2 ($F(1, 30) = 14.16$, $p = .001$) and in block 3 ($F(1, 32) = 4.24$, $p = .048$). In block 2, children performed over chance level in SVO sentences ($t(31) = 3.79$, $p = .001$) and at chance level in OVS sentences ($t(32) = -1.60$, $p = .119$). In block

3, they pointed at above-chance level in OVS sentences (*t*(33) = 2.17, *p* = .038) and at chance level in SVO sentences (t(32) = -1.23, *p* = .228). The processing of syntactic structures during experimental session was not related to the age of children, as assessed by ANOVA with factors Syntax (2), Block (5) and Age (2).

Children's performance in conditions with animacy cue did not differed between blocks, as was confirmed by ANOVA with factors Syntax (2), Agent Animacy (2) and Block (5). Apart from effect of Syntax (*F*(1, 16) = 5.23, *p* = .036) and Agent Animacy (*F*(1, 16) = 7.95, *p* = .012), no other effects were found. The accuracy of response in these conditions did not differ significantly between younger and older 2-year-olds, as assessed by ANOVA with factors Syntax (2), Agent Animacy (2), Block (5) and Age (2).

The second analysis evaluated the trials that did not receive unambiguous response in picture-matching task. This data included items, in which the child pointed to either pictures, or the child was undecided about the choice, or the child did not look at the picture, or the child did not listen to the stimulus sentence. The number of such trials increased toward the end of the experimental session in 2-year-old children (Figure 4.2.6). This was confirmed by one-way ANOVA with factor Block (*F*(1.64, 53.99) = 4.28, *p* = .025). This effect was driven by differences between the number of missed trials in block 1 and block5 (*t*(33) = -2.07, *p* = .046), block 2 and block 5 (*t*(33) = -2.34, *p* = .025), block3 and block 4 (*t*(33) = -2.18, *p* = .037), and block 3 and block 5 (*t*(33) = -2.47, *p* = .019). When the between-subject factor of Age was included into analysis, the main effect of Block (*F*(1.82, 51.04) = 3.38, *p* = .046) and the main effect of Age (*F*(1, 28) = 10.97, *p* = .003) were significant. The interaction between Block and Age was marginally significant: *F*(1.82, 51.04) = 2.81, *p* = .074. In younger 2-year-olds, there were marginally significant differences in children's response capacities between blocks 2 and 5 (*t*(14) = -2.09, *p* = .055) and blocks 3 and 5 (*t*(14) = -2.12, *p* = .052).

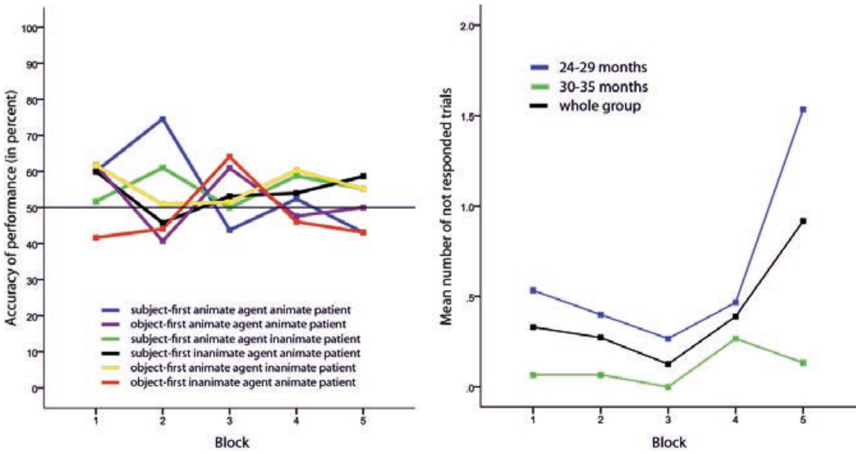


Figure 4.2.6. Mean accuracy of performance in five blocks of the experiment. The horizontal line indicates the chance level of 50%.

Discussion

Experiment 2a aimed to examine the ability of 2-year-old children to interpret canonical and non-canonical transitive sentences. In the picture-matching task, children were presented with [NP – Verb – NP] structures, in which subject-object word order was manipulated yielding two types of sentences: subject-first (SVO) and object-first (OVS) sentences. Agent and patient were unambiguously marked by the respective case forms *der* and *den*. In one third of sentences, the animacy contrast was neutralized, that is, both participants were animals. In another two thirds of sentences, the animacy contrast was available. In half of these sentences, the animacy contrast was congruently mapped on thematic roles, that is, the agent was animate and the patient was inanimate. In the other half, the semantic contrast was incongruent with an inanimate agent and an animate patient.

Table 4.2.3 summarizes the results of the picture-matching task with 2-year-olds. The whole-group analysis showed that children performed at above-chance level in SVO sentences with congruent animacy contrast, e.g., *Der Tiger schiebt den Turm*. ‘The.NOM tiger pulls the.ACC tower’. Such sentences contained three cues for thematic role assignment, including case marking, position and animacy contrast. All of them worked in coalition directing to the interpretation of the first argument as agent. Participant’s age was positively related to the performance in such structures, indicating that the group effect was driven by the pointing behaviour of children older than 29 months. Thus, children at the age of two in our study were able to interpret prototypical subject-first sentences with animate agent and inanimate patient.

Table 4.2.3. Two-year-olds' pointing behavior as compared to the chance level of 50%.

Condition		**Cues**	**24–29 months**	**30–35 months**
Syntactic manipulation	Subject-first	C, WO	○	○
	Object-first	C	○	○
Syntactic-semantic manipulation	Subject-first animate agent	C, WO, A	○	+
	Subject-first inanimate agent	C, WO	○	○
	Object-first animate agent	C, A	○	○
	Object-first inanimate agent	C	○	○

Note. C, case marking; WO, word order; A, animacy contrast; ○, behavior at chance level; +, behavior above chance level.

These findings were consistent with the coalition-as-prototype hypothesis, according to which 'subject' is defined as a coalition of many-to-many mappings between the function and form (Bates & MacWhinney, 1987, p.166). Furthermore, our experiment showed that the ability to correctly respond to SVO sentences with prototypical semantic cues was guided by sensitivity to the animacy contrast. While the group of younger two-year-olds did not seem to attend to animacy, the older 2-year-olds performed better in sentences with congruent animacy contrast than in sentences with incongruent animacy contrast (inanimate patient and animate patient). These results were in line with the studies that suggest that animacy substantially contributes to sentence interpretation in early childhood (Chan et al., 2009; Lindner, 2003). The current study was the first to show that children's attention to the animacy cue during sentence interpretation develops within the third year of life.

The failure of the younger half of 2-year-olds to perform correctly in SVO sentences with a congruent animacy contrast has an alternative paradigmatic explanation. The animate-inanimate distinction in the picture material might have not been clear-cut for 24- to 29-month-old children. Some inanimate objects in the visual stimuli received animate-like features that might obscure the distinction between animates and inanimates. Specifically, several inanimate objects had animalistic details, including animal-like extremities and teeth. Previous research on categorization in infants showed that they are sensitive to such static attributes as legs, heads and tails (Rakison & Poulin-Dubois, 2001). For example, in the study by Rakison and Butterworth (1998), infants between 14 and 22 months of age differentiated between animals and vehicles when animals had legs and vehicles had wheels. However, infants failed to form categories if the body part differences were absent (i.e., all entities had legs or wheels, or body parts were absent in all entities). It may be the case that in the present visual materials the differentiation between animates and inanimates based on these static features was disturbed in children between 24–29 months of age. Thus, its implication for sentence interpretation might be limited in very young 2-year-olds.

Contrary to our expectations, children in the study did not perform well in all SVO sentences with animate agent. Their response was at chance level in conditions with neutralized animacy, e.g., *Der Tiger zieht den Hund*. ‘The.NOM tiger pulls the.ACC dog’. This result differed from the study by Dittmar et al. (2008), in which 2;6- to 2;8-year-old children pointed correctly (76%) in sentences of type *Der Hund wieft den Löwen.* ‘The dog.NOM is weefing the.ACC lion’. In fact, the accuracy of performance for such structures in the current study fluctuated considerably during the testing session. Above-chance performance was achieved only at the beginning of the experiment.

There are several possible explanations for the discrepancy between the present results and previous findings. On the one hand, near-chance accuracy might be explained by tiredness. Although pointing is a naturally developing ability in infants that is present at the age of 8–12 months (Liszkowski & Tomasello, 2011; Tomasello, Carpenter, & Liszkowski, 2007), the task of considerable length might have been very demanding for our participants due to the high memory, attention and motor efforts. To our knowledge, the youngest groups that were tested in the pointing paradigm included children between 1;11–2;4 years (M_{age} = 2;3) in the study by Noble et al. (2011) and children between 2;0–2;2 years (M_{age} = 2;1) in the study by Dittmar et al. (2011). In these experiments, children were exposed to eight and six test trials, respectively. In our experiment, five blocks each containing six items (i.e., in total 30 items) were presented. Data supporting the impact of fatigue comes from the analysis of items that did not have a response during testing session. Two-year-old's ability to give an unambiguous answer decreased markedly toward the end of the experiment. The whole-group decline of attention and pointing capacities appeared to be driven by the behaviour of younger participants between 24–29 months. Corroborating conclusions were drawn in the study by Dittmar et al. (2011), who showed that the ability to understand transitive structures with novel verbs by 2-year-old children was related to their age and the robustness of their ability to override fatigue during testing procedure. Younger 2-year-olds were argued to have difficulties in accommodating a novel verb during a long experimental session. While 2;7-year-olds performed well in a 15-minute experiment with six critical items, 2;1-year-olds showed comparable behaviour only in the first four trials.

On the other hand, the factor of fatigue seemed to play a minor role for interpretation of SVO sentences with animacy contrast. Children's performance in such structures did not change significantly during the experimental session. In line with the coalition-as-prototype hypothesis, two-year-olds appeared to benefit from the presence of the additional animacy contrast that was not manipulated in the study by Dittmar et al. (2008). While SVO sentences without animacy contrast required more cognitive effort and were more influenced by fatigue, SVO sentences with congruent animacy contrast were less demanding for our participants. Therefore, the context of the experiment, that is, the presence of sentences with additional cues, might explain the inconsistency in the interpretation of simple transitive sentences with neutralised animacy.

As expected, 2-year-olds responded with near-chance accuracy in OVS sentences in either the condition with and without animacy contrast. Although age was positively related to the performance in OVS sentences with congruent animacy contrast, older 2-year-olds did not systematically point to the correct picture for complex sentences with supporting semantic cue. In line with other studies on the use of case marking (Dittmar et al., 2008), our results indicated that the functional meaning of case is not yet available in children's linguistic knowledge at the age of two years. Furthermore, children did not use systematically a word order strategy when making a choice between pictures. The consequent use of a SVO word order strategy would result in the below-chance performance in OVS sentences with neutralized animacy. This was not the case in our study. Children’s choice was not guided by a positional cue.

In sum, the behavioural study with 2-year-olds showed that at the end of their third year, children were able to respond correctly to prototypical SVO sentences with an animate-inanimate contrast. Their sentence interpretation relied on congruent semantic information cueing. Sensitivity to animacy was strongly related to the age of the participants. Two-year-olds, however, did not consistently used the semantic cue for the interpretation of complex sentences.

4.3 Experiment 2b: 3-year-olds

The ability of 3-year-old children to interpret complex sentences was examined in Experiment 2b. Children’s performance in picture-matching task was tested for purely syntactic contrasts as well as for syntactic-semantic manipulation. Based on the previous literature and the results of the behavioral study with 2-year-olds, we hypothesized that in sentences without animacy contrast, 3-year-olds will perform

- over chance level in SVO sentences, indicating their ability to interpret simple transitive sentences with animate agent, that is, sentences with multiple cooperating cues (Dittmar et al., 2008; Schipke et al., 2012);
- with near-chance or below-chance accuracy in OVS condition, as reflecting the lack of ability to use case markings for sentence interpretation without supporting contrastive cue of animacy (Dittmar et al., 2008; Schipke et al., 2012);
- better in SVO than in OVS conditions, as reflecting children’s sensitivity to case marking (Mahlstedt, 2008).

In sentences with the animacy contrast, 3-year-olds were expected to perform

- over chance level in SVO structures with animate agent (Dittmar et al., 2008; Schipke et al., 2012);
- better in SVO than OVS sentences (Mahlstedt, 2008);

- better in conditions with congruent semantic contrast (animate agent/inanimate patient) than in conditions with incongruent semantic contrast (inanimate agent/animate patient) (Lindner, 2003).

Methods

Participants

The behavioral task was conducted with 56 three-year-old children. The data of 21 three-year-olds was excluded from the analysis due to hearing disease history (four children), bilingual environment (one child), missing data on language development (nine children), low performance on language development test TSVK (one child), and one-side bias in the pointing behavior (four children). The data of three children were excluded due to statistically exceptionally low (one child) and high performance (two children) in the picture-matching task. Their mean accuracy for the entire experiment lied behind 1.5 standard deviations from the mean value. The final analysis was conducted with the data of 32 three-year-old children (age range 37–46 months, M_{age} = 41.44 months, *SD* = 2.65 months, 18 girls).

Children's language abilities were assessed using a screening version of TSVK (Siegmüller et al., 2010). The test was conducted during a separate session by a native-language speaker. Thirty-six sentences were presented in picture-matching task with three-picture arrays assessing the ability of children to understand transitive verb-argument structures, active/passive constructions, complex subordinate structures and tense forms. Three-year-olds had a mean raw score of 19.16 with the range 13–26, *SD* = 3.66. The mean normed score was 79.16, range 51–99, *SD* = 15.68.

Materials

Experiment 2b used the same materials as Experiment 2a. Stimulus sentences were evenly distributed in five lists that were randomly assigned to the participants. Each list contained 36 sentences, so that individual conditions were presented by six experimental items. Additional five lists were created by reversing the order of the items. In the reversed lists, the target side and direction of action was changed.

Hence, experimental materials for 3-year-old children included 10 versions of stimulus material.

Procedure

Experimental procedure only slightly differed from that in Experiment 2b. Three-year-old children were seated in the cabin alone. In very rare cases, parents were seated in the cabin behind the child to avoid visual contact.

Data analysis

Data was analyzed with the same coding parameters as in 2-year-olds. Forty-six trials (2.32 % of data) had to be excluded from the analysis, since they did not receive unambiguous response. These included eight SVO and nine OVS structures in syntactic comparison; as well as seven SVO sentences with animate agent, six SVO sentences with inanimate agent, eight OVS sentences with animate agent, and eight OVS sentences with inanimate agent. The accuracy score was calculated using the formula: $\frac{Ncorrect}{6-Nmiss} * 100$.

Statistical evaluation of response accuracy was conducted using the same tests as in the analysis of 2-year-olds' data (see section *Data analysis* in Chapter 4.2).

Results

Syntactic contrast

Three-year-olds' accuracy for SVO structures was significantly higher than for OVS structures ($t(1, 34) = 16.57$, $p < .001$, Figure 4.3.1). They performed over chance level of 50% in SVO sentences ($t(31) = 8.70$, $p < .001$). Comparison of the accuracy in OVS sentences to chance level was not significant: $t(31) = 1.51$, $p = .141$.

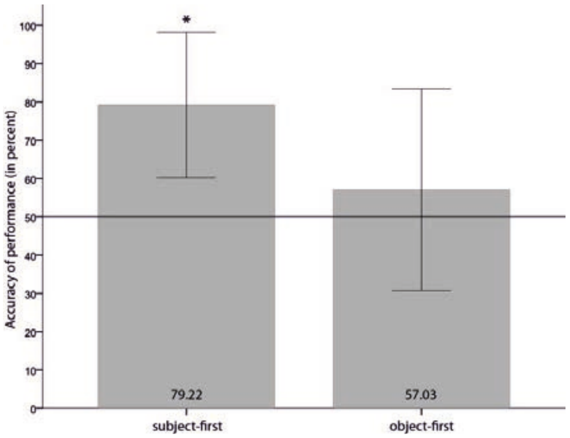


Figure 4.3.1. Mean accuracy of performance in picture-matching task by 3-year-old children in subject-first and object-first conditions with neutralized animacy. Error bars indicate one standard deviation (SD). Asterisk indicates over-chance level performance, as assessed by one-sample t-test, $p < .05$.

While children’s performance in OVS condition correlated positively with age ($r = .66$, $p < .001$, Figure 4.3.2), no such correlation was found for SVO sentences ($r = .06$, $p = .748$). In order to explore this relationship in detail, the group of 3-year-olds was split into two age groups of equal size: younger 3-year-olds (37–41 months, $n = 15$) and older 3-year-olds (42–47 months, $n = 15$). The data of two participants distributed at and close to median was excluded from the analysis. Group differences were tested using repeated measures ANOVA with within-subject factor Syntax and between-subject factor Age. The effect of Age and interaction Age × Syntax were significant ($F(1, 28) = 11.56$, $p = .002$ and $F(1, 28) = 13.26$, $p = .001$, respectively). Separate analyses of variance showed that only younger children processed SVO sentences significantly better than OVS sentences ($F(1, 14) = 44.91$, $p < .001$). Older 3-year-olds did not show effect of syntax ($F(1, 14) = .71$, $p = .412$). Both groups performed over chance level in SVO condition (younger 3-year-olds: $t(14) = 6.99$, $p <.001$; older 3-year-olds: $t(14) = 5.02$, $p <.001$). However, only older children performed over chance level in OVS sentences ($t(14) = 4.77$, $p < .001$). The accuracy of performance by younger 3-year-olds was significantly below chance level: $t(14) = -2.40$, $p = .031$, Figure 4.3.2). Furthermore, children’s accuracy in OVS sentences was related to age in the younger (*r* = .54, *p* = .038), but not in the older subgroup of three-year-olds.

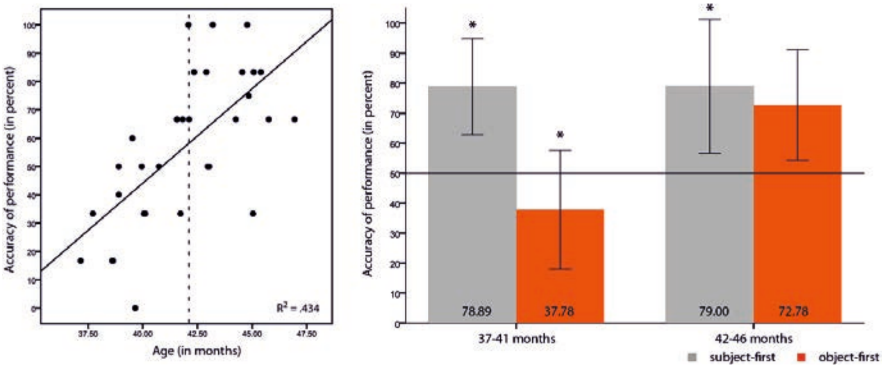


Figure 4.3.2. Accuracy of performance relative to age in 3-year-old children. Left panel: Relationship between performance in subject-first sentences with neutralized animacy and children's age. Right panel: Age groups as calculated by median-split analysis. Asterisk indicates relation to chance level performance, as assessed by one-sample t-test, *p* < .05.

There was a positive relationship between the accuracy in subject-first structures and performance in language test TSVK (*r* = .37, *p* = .040), but no such relationship between the accuracy in object-first structures and TSVK (*r* = -.13, *p* = .486). No differences between girls' and boys' performance were found, as assessed by mixed ANOVA with factors Syntax and Gender (Syntax × Gender: *F*(1, 30) = 0, p = .995).

Syntactic-semantic contrast

The analysis of variance with factors Syntax and Agent Animacy revealed the main effect of Syntax (*F*(1, 31) = 21.20, *p* <.001) and effect of Animacy (*F*(1, 31) = 5.08, *p* = .031). No interaction between factors was found (*F*(1, 31) = .10, *p* = .763).

Three-year-old children performed over chance level in both SVO conditions (SVO with animate agent: *t*(31) = 8.83, *p* <.001; SVO with inanimate agent: *t*(31) = 4.29, *p* < .001, Figure 4.3.3), but also in OVS sentences with animate agent (*t*(31) = 2.07, *p* = .047). The accuracy for OVS sentences with inanimate agent was near to chance: *t*(31) = .12 , *p* = .906.

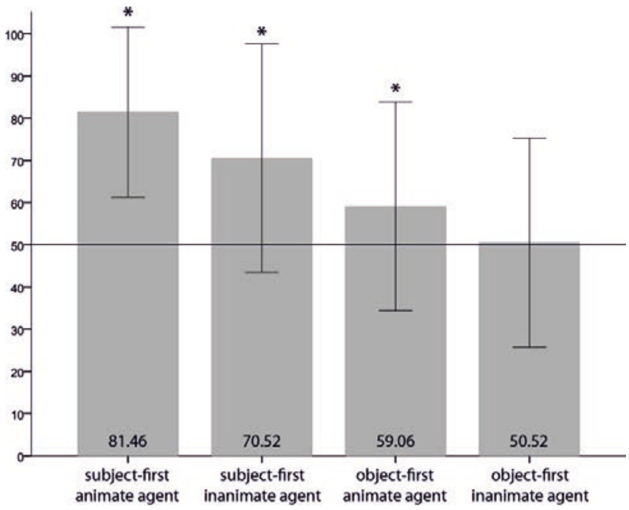


Figure 4.3.3. Mean accuracy of performance in picture-matching task by 3-year-old children in subject-first and object-first conditions with animacy contrasts. Error bars indicate one standard deviation (SD). Asterisk indicates over-chance level performance, as assessed by one-sample t-test, *p* < .05.

Correlational analyses revealed no relationship between age and performance in neither of conditions with animacy contrast (*r* = .05−.31, *p* = .084−.419). Nevertheless, the analysis of responses in age subgroups (37- to 41-month-olds versus 42- to 47-month-olds) showed that the high whole-group accuracy of performance in OVS sentences with congruent animacy contrast was driven by the older half of 3-year-olds. In contrast to the younger half, whose accuracy in this condition was at 50%, older 3-year-olds responded correctly with 65% above chance level (*t*(14) = 2.55, *p* = .023). Both age subgroups systematically identified correct picture in SVO conditions, independently of animacy contrast (younger 3-year-olds: SVO animate agent *t*(14) = 4.41, *p* = .001, SVO inanimate agent *t*(14) = 2.93, *p* = .011; older 3-year-olds: SVOt animate agent *t*(14) = 8.56, *p* < .001, SVO inanimate agent *t*(14) = 3.50, *p* = .004).

There was a positive relationship between children’s language development (TSVK score) and their performance in canonical SVO structures with animate agent: *r* = .35, *p* = .049. TSVK score was correlated with the performance in OVS structures with animate (*r* = .35, *p* = .052), but not with inanimate agent (*r* = .11, *p* = .558). No differences between girls’ and boys’ performance in these conditions were observed, as indicated by repeated measures ANOVA with between-subject factor Gender: *F*(1, 30) = 1.74, *p* = .196).

Dynamics of performance

In the picture-matching task, three-year-old children were asked to point in 36 critical trials. The sentences were organized in six blocks, each testing all six conditions. The performance dynamics was assessed from two perspectives, including the analysis of response and non-response data.

Figure 4.3.4 represents the accuracy of responding to all conditions across six experimental blocks. A clear difference between responses to SVO and OVS structures can be observed. However, the performance did not change significantly across conditions in either the structure with and without animacy contrasts. This was confirmed by ANOVA with factors Syntax (2) and Block (6) for purely syntactic manipulation that revealed the main effect of Syntax (*F*(1, 25) = 12.96, *p* = .001) but no significant interaction Syntax × Block (*F*(5, 125) = .20, *p* = .961). Similarly, no significant interactions with factor Block (6) were found in the analysis of data with animacy contrasts. No differences were found between age subgroups in either syntactic or syntactic-semantic manipulation.

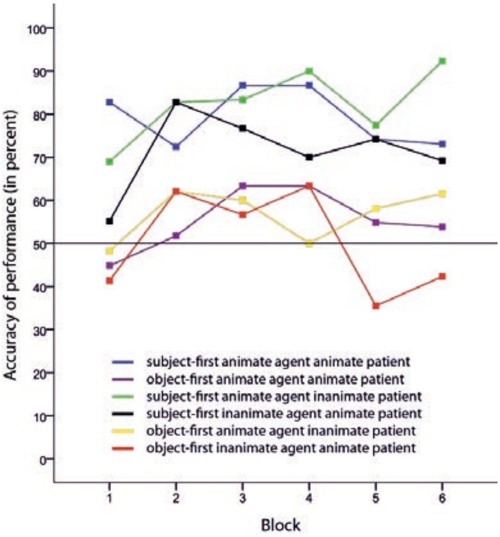


Figure 4.3.4. Mean accuracy of performance by 3-year-old children in picture-matching task across six experimental blocks. The horizontal line indicates the chance level of 50%.

The number of not-responded items increased from 0.094 to .344 across six trials. Differences between blocks, however, were not significant, as assessed by one-way ANOVA ($F(1.49, 46.04) = 1.59$, $p = .217$). Neither was there a relationship between the number of missed trials and the age of participants, as confirmed by ANOVA with between-factor Age.

Discussion

The purpose of Experiment 2b was to examine the behavioural response of 3-year-old children to sentences with SVO/OVS word orders with and without animacy contrast. Similarly to 2-year-olds, the participants were tested in the picture-matching task, in which they were presented with short transitive structures. The animacy cue was either available (purely syntactic contrast) or not (syntactic-semantic contrast).

Children at the age of three were able to correctly point in SVO conditions with congruent animacy contrast, thereby showing a developmentally coherent response to prototypical sentences with multiple cooperating cues (Table 4.3.1). These results were consistent with the coalition-as-prototype model that postulated an early acquisition of structures with syntactic and semantic cues working in coalition (Bates & MacWhinney, 1987; Dittmar et al., 2008).

Table 4.3.1. Three-year-olds' pointing behavior as compared to the chance level of 50%.

Condition		**Cues**	**37–41 months**	**42–47 months**
Syntactic manipulation	Subject-first	C, WO	+	+
	Object-first	C	-	+
Syntactic-semantic manipulation	Subject-first animate agent	C, WO, A	+	+
	Subject-first inanimate agent	C, WO	+	+
	Object-first animate agent	C, A	○	+
	Object-first inanimate agent	C	○	○

Note. C, case marking; WO, word order; A, animacy contrast; "○", behavior at chance level; "-", behavior below chance level; "+": behavior above chance level.

Younger 3-year-old children performed systematically well in the conditions with the two cooperating cues of case and word order, but not in the condition with cooperating case and animacy. The reliance on the positional cue at this stage was also observed in OVS sentences with neutralized animacy contrast, in which young 3-year-olds systematically made mistakes (38%). Accuracy of performance in such sentences was related to age. This pattern pointed to the use of the word order strategy by children at the beginning of their fourth year. Attention to the argument position was not surprising given previous studies that investigated the use of word order for sentence interpretation. The older half of the 2-year-olds tended to choose the first argument as agent in sentences with neutralized animacy and novel verb in the act-out task by Chan et al. (2009). Young three-year-olds (range 2;8–3;2) pointed below chance level in OVS sentences with neutralized animacy in the study by Schipke et al. (2012). Similar results were obtained by Watermeyer, Höhle, and Kauschke (2011) with 3;0- to 3;5-year-old children. Corpus-based analyses of child-directed speech demonstrated that in 68% of transitive sentences, word order and case- marking referred to the first argument as agent (Dittmar et al., 2008, Study 1). Finally, word order was shown to be a reliable cue for sentence interpretation by adults if the cues of case marking and animacy were neutralized (MacWhinney et al., 1984). To summarize, younger 3-year-olds were not yet able to use case marking to interpret complex sentences. When the animacy cue was not available, they rather attended to the positional cue.

In contrast to the findings on the emerging use of case marking around 5−6 years (Dittmar et al., 2008; Lindner, 2003), older 3-year-old children (42−47 months) in our study pointed correctly above chance level in OVS conditions both with (65%) and without (73%) cooperating animacy cue[10]. These results indicated that children at the end of their fourth year were able to use case marking for interpretation of complex sentences. The presence of the animate agent was sufficient for older 3-year-olds to correctly respond to such structures.

High accuracy of response in OVS sentences might be alternatively attributed to the fact that all children received a behavioural task after the electrophysiological experiment, in which the same structures appeared in 50% of stimulus sentences. The very recent exposure to the syntactic structure might have increased the likelihood of understanding and correct pointing in OVS sentences in older 3-year-olds. Some support for this interpretation may be found in developmental studies that used a syntactic priming paradigm (for review, see Vasilyeva,

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[10] Post-hoc paired t-test revealed no significant differences between accuracy rates in object-first sentences with and without animacy contrast ($t(14) = -1.647$, $p = .122$).

Waterfall, & Gómez, 2011). For example, Shimpi, Gamez, Huttenlocher, and Vasilyeva (2007) explored such effects with English-speaking 3- and 4-year-old children in the domain of active/passive transitive and dative structures. In one of their experiments, children were not asked to repeat the prime. While 4-year-old children (range 3;8–4;6) showed a robust priming effect in this experiment, 3-year-olds (range 2;6–3;6) were not sensitive to the experimenter's use of dative structure. However, 3-year-old children showed priming effect in the experiment, in which they were asked to repeat the prime immediately after the experimenter. Similar priming effect in prime-repetition procedure was observed by Bencini and Valian (2008) with 2;11- to 3;6-year-olds. English-speaking 4-year-old children (range 4;0–4;7) demonstrated priming effects with active and passive sentences without prime repetition in the study by Savage, Lieven, Theakston, and Tomasello (2003), in which there was a high lexical overlap between prime and target. Experiments by Huttenlocher, Vasilyeva, and Shimpi (2004) with 4-year-olds (range 4;1–5;7) also showed that priming was preserved over the set of 10 trials. Finally, syntactic priming effects were found in 2-year-old (range 2;7–2;11) German-speaking children for simple transitive structures of type *Baby kitzeln* 'tickling a baby' (Foltz, Knopf, Thiele, & Stenneken, 2012).

To our knowledge, no developmental studies explored the priming effects in the domain of case acquisition. However, in the study by Knoll et al. (2012), a very similar tendency as in the present experiment was observed. The authors conducted the picture-matching experiment after an fMRI scanning session, in which 4;8- to 6;8-year-olds were exposed to SVO and OVS sentences with inanimate participants. Children performed over chance level in both SVO (94%) and OVS (71%) conditions showing the ability to use the cue of case marking for sentence interpretation. If the effect obtained in our study and the study by Knoll et al. (2012) were due to priming, the findings might indicate that abstract syntactic representations of two-argument transitive structures are present in older 3-year-old children.

Finally, the results of the experiment indicated that 3-year-olds are sensitive to the semantic features of agent/patient roles in complex syntactic contexts. This was evidenced by their performance in OVS sentences with congruent animacy contrast, such as *Den Topf schiebt der Tiger.* ‘The.ACC pan pulls the.NOM tiger’. Younger 3-year-olds performed at chance level in this condition (50%). One can speculate that in situations where animacy of the noun was irrelevant for their behaviour, they would perform below chance level in such sentences, as they did in OVS conditions with two animate arguments. This was not the case in the current study. Moreover, older 3-year-olds showed a more mature response in complex sentences with congruent agency, indicating that noun animacy supported the use of syntactic markers. These results were consistent with the data obtained by Lindner (2003) and Mahlstedt (2008), who showed a sensitivity of 3-year-olds to noun animacy in an act-out task. Although 3-year-olds were not able to use determiners in sentences in which it was the only marker of thematic relationships, they appeared to be aware of the functional meaning of case marking for sentence interpretation.

Taken together, the results of the picture-matching experiment with 3-year-olds revealed age-related differences in the use of grammatical and semantic features. While younger 3-year-olds seemed to ignore case marking in favour of word order, this strategy was abandoned by the end of the fourth year. In contrast to 2-year-old children, who attended to the noun animacy when interpreting simple sentences, the semantic cue became a more influential cue for interpretation of complex sentences in 3-year-olds. The ability of 3-year-olds to integrate semantic-grammatical information indicated their general awareness of the functional meaning of case marking for assignment of thematic roles.

4.4 Age-related differences in behavioural processing of case marking and animacy

Previous sections presented separate detailed analyses of the behavioural response to complex sentences in 2- and 3-year-old children. The current analysis aims to evaluate the global developmental trajectory of syntactic and semantic processing between 24 and 35 months.

Data analysis

Four datasets were included into the comparative analysis. They consisted out of the data of 15 younger and 15 older 2-year-olds as well as the data of 15 younger and 15 older 3-year-olds. A repeated measures ANOVA with factors Syntax (2) and between-subject factor Age (4) was conducted to explore developmental differences in the use of case marking. Syntactic-semantic cues were examined using a repeated measures ANOVA with factors Syntax (2), Agent Animacy (2) and between-subject factor Age (4). The development of response to specific conditions was assessed using independent samples t-tests.

Results

Syntactic contrast

Figure 4.4.1 summarizes the accuracy of performance for SVO and OVS sentences without animacy contrast across age subgroups. Repeated measures ANOVA with factors Syntax (2) and Age (4) revealed the main effect of Syntax ($F(1, 56) = 10.35$, $p = .002$), the main effect of Age ($F(3, 56) = 6.03$, $p = .001$) and Syntax × Age interaction ($F(3, 56) = 6.03$, $p = .001$). Interaction between Syntax and Age was driven by accuracy differences in the group of younger 3-year-olds ($F(1, 14) = 44.91$, $p < .001$).

Bonferroni-corrected post hoc tests showed that the accuracy of performance did not significantly differ between younger 2-year-olds, older 2-year-olds and younger 3-year-olds. However, in older 3-year-olds the pointing accuracy was greater than in younger 2-year-olds ($p = .009$), older 2-year-olds ($p < .001$) and younger 3-year-olds ($p = .008$).

Significant developmental changes occurred in SVO sentences between older half of 2-year-olds and younger half of 3-year-olds ($t(28) = -4.38$, $p < .001$). This developmental tendency was also supported by the positive correlation between the accuracy of response in SVO sentences and age of participants ($r = .47$, $p < .001$). As was shown in earlier analyses, differences in response to OVS sentences were significant between younger 3-year-olds and older 3-year-olds ($t(28) = -5.01$, $p < .001$, independent samples t-test).

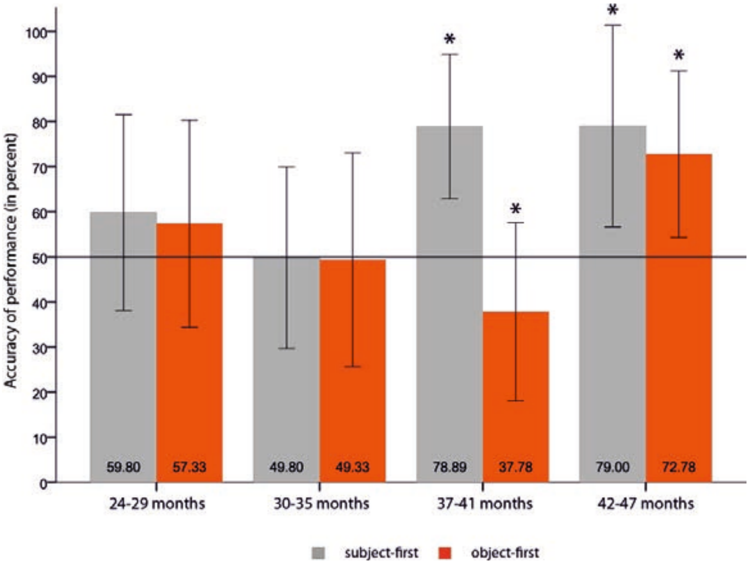

Figure 4.4.1. Comparison of performance accuracy in the syntactic manipulation to the chance level across age groups. Asterisk indicates significant deviation from chance level, as assessed by one-sample t-test, $p < .05$.

As has been shown in the individual group analyses, the younger half of 3-year-olds performed over chance level in SVO ($p < .001$) and below chance level in OVS sentences ($p = .031$). Older 3-year-olds were above chance level in both conditions ($p < .001$).

The accuracy of response to OVS sentences decreased between 24 and 41 months (Figure 4.4.1). This tendency was supported statistically by significant correlation between the age of participants and pointing accuracy: $r = -.29$, $p = .043$. That is, children's pointing accuracy in complex sentences with neutralized animacy decreased as a function of age.

Syntactic-semantic contrast

Figure 4.4.2 presents a summary of performance accuracy in syntactic-semantic manipulation. ANOVA with Factors Syntax (2), Agent Animacy (2) and Age (4) revealed the main effect of Age ($F(3, 56) = 9.66$, $p < .001$), the main effect of Syntax ($F(1, 56) = 31.62$, $p < .001$) and marginally-significant effect of Agent Animacy ($F(1, 56) = 3.45$, $p = .069$, see also Figure 4.4.3).

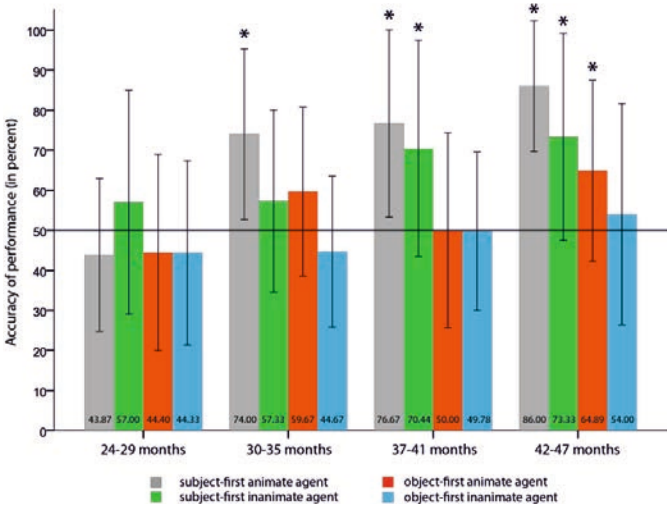

Figure 4.4.2. Comparison of performance accuracy in syntactic-semantic manipulation to the chance level across age groups. Asterisk indicates significant deviation from chance level, as assessed by one-sample t-test, *p* < .05.

The interactions Syntax × Age, Syntax × Animacy × Age were not significant. The interaction Animacy × Age was marginally significant: *F*(3, 56) = 2.30, *p* = .088. It was mainly driven by animacy effects in older 2-year-olds (*F*(1, 14) = 4.95, *p* = .043) and in older 3-year-olds (*F*(1, 14) = 4.73, *p* = .047, Figure 4.4.3, lower panel). Bonferroni-corrected post-hoc tests revealed that the performance of younger 2-year-olds was significantly poorer that of the older 2-year-olds (*p* = .047), of the younger 3-year-olds (*p* = .007) and of the older 3-year-olds (*p* < .001).

Individual group analyses showed that older 2-year-olds and all 3-year-olds performed above chance level in SVO structures with congruent animacy contrast (older 2-year-olds: *t*(14) = 4.36, *p* = .001; younger 3-year-olds: *t*(14) = 4.41, *p* = .001; older 3-year.olds: *t*(14) = 8.56, *p* < .001). Three-year-old children performed over chance level in SVO sentences with inanimate agent (younger half: *t*(14) = 2.93, *p* = .001; older half: *t*(14) = 3.50, *p* = .004). The oldest group of participants performed over chance level in OVS sentences with animate agent (*t*(14) = 2.55, *p* = .023).

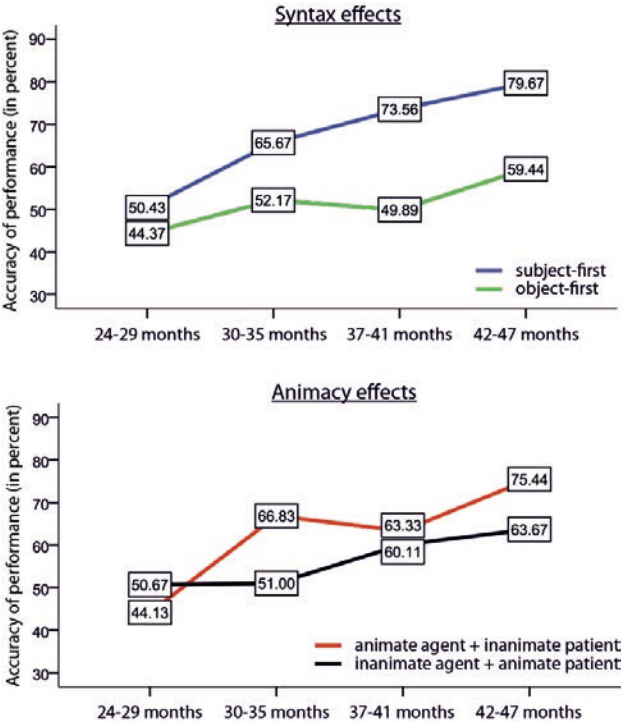

Figure 4.4.3. Developmental trajectory of pointing accuracy for subject-first and object-first sentences (upper panel) as well as sentences with congruent and incongruent animacy contrast (lower panel).

Analysis of the relationship between age and performance in syntactic-semantic conditions revealed a significant correlation between age and accuracy in SVO sentences with congruent animacy contrast ($r = .60$, $p < .001$), between age and accuracy in SVO sentences with incongruent animacy contrast ($r = .26$, $p = .039$) and between age and accuracy in OVS sentences with congruent animacy contrast ($r = .25$, $p = .042$).

Discussion

Table 4.4.1 presents a summary of participants' pointing behaviour, as described in previous chapters and the current *Results* section. It is obvious that children's ability to correctly identify agents and patients develops with age. Children's reliance on linguistic cues appeared to change considerably during 24 months. Whereas younger 2-year-olds did not use any of the available cues systematically, the older half of this age group was able to interpret sentences in which all three available role markers cooperated. Younger 3-year-olds pointed correctly in conditions with two cooperating cues, while older 3-year-olds correctly assigned roles in sentences with one cue. This data demonstrates an age-related reduction of a number of cooperating cues that are required for correct sentence interpretation in young children.

Table 4.4.1. Children's pointing behavior as compared to the chance level of 50%.

Condition		**Cues**	**Correlation**	**24–29 m.**	**30–35 m.**	**37–41 m.**	**42–47 m.**
Syntactic manipulation	Subject-first	C, WO	~ age	○	○	+	+
	Object-first	C		○	○	-	+
Syntactic-semantic manipulation	Subject-first animate agent	C, WO, A	~ age	○	+	+	+
	Subject-first inanimate agent	C, WO	~ age	○	○	+	+
	Object-first animate agent	C, A	~ age	○	○	○	+
	Object-first inanimate agent	C		○	○	○	○

Note. C, case marking; WO, word order; A, animacy contrast; "○", behavior at chance level; "-", behavior below chance level; "+", behavior above chance level.

Children's use of case marking showed an interesting trajectory. As expected, our youngest participants (24–35 months) did not have any preference when pointing in OVS conditions. With increasing age, children neglected case marking while focusing on the position of the argument in sentence (37–41 months). Children at the middle of their fourth year (42–47 months) started to use grammatical cues in complex sentences with a prototypically animate agent. However, the acquisition of case marking was not completed during the second half of the fourth year. This was evidenced by children's random pointing in OVS sentences with incongruent animacy contrast, such as *Den Tiger schiebt der Turm*. 'The.ACC tiger pulls the.NOM tower'. Our oldest participants were not yet able to resolve the conflict between case marking, word order and animacy.

This pattern also indicated that children remain sensitive to the animacy contrast during yearly development. The trajectory of reliance on this cue, however, seems to be more complex than reported previously in studies that investigated the role of noun animacy in sentence processing in 2- and 3-year-old children (e.g., Lindner, 2003). The role of the semantic cue appeared to strengthen during the third year of life. The older half of the 2-year-olds attended to the animacy contrast only when interpreting simple SVO sentences. The pointing behaviour of younger 3-year-olds underwent a transition: the congruency of the animacy contrast was already irrelevant for interpretation of simple sentences, but not yet influential enough for interpretation of complex structures. Older 3-year-olds appeared to rely on noun animacy in complex OVS conditions.

4.5 Conclusion

In a series of picture-matching experiments, we investigated the role of syntactic and semantic cues for sentence interpretation during early development. The analyses of the data suggest that children gradually but rapidly acquire the functional meaning of nominative and accusative case between 24 and 47 months of age. Initially, children do not attend to grammatical markers when interpreting complex sentences. Their pointing behavior at that age proceeds through the stage of “neglecting”, in which word order strategy has more impact on the assignment of thematic roles. Children between 42–47 months of age start to use case marking for their overt behavioral response.

Attention to the animacy of the agent arises between 30 and 35 months and remains an influential cue for sentence interpretation throughout the next year. Children at the end of their third year rely on animacy contrast for their interpretation of simple sentences. At the end of the fourth year, animacy contrast supports the role assignment in complex OVS structures.

5 The processing of case marking in sentential context: ERP study

5.1 Introduction

The present ERP study aimed at tracking developmental differences in the reliance on syntactic and semantic information when assigning thematic roles during sentence processing. It investigated electrophysiological correlates of case marking and animate/inanimate distinction in sentential contexts with adults and 2- to 3-year-old children. The neural response to the syntactic-semantic manipulation was related to their ability to use these cues for an overt behavioral response.

This chapter is structured as follows. The first sections review the main neurophysiological findings on the syntactic processing in adults and children, as well as the data on the processing of semantic cues with focus on animacy. The part *Current study* provides details on the present experimental design and materials. It is followed by three sections, in which the results of experiments for individual age groups (Experiment 3a – Experiment 3c) are presented and discussed.

Neurophysiological evidence on case processing in adults and children

The processing of case marking in adults

Adult syntactic parsing was shown to be sensitive to variations of case marking and word order in cross-linguistic neurophysiological studies. These were conducted in two main areas with focus on morphosyntactic violation on the one hand (e.g., Coulson, King, & Kutas, 1998; Frisch & Schlesewsky, 2001; Mueller, Hirotani, & Friederici, 2007; Schipke, Friederici, & Oberecker, 2011), and syntactic complexity on the other (e.g., Erdocia, Laka, Mestres-Misse, & Rodriguez-Fornells, 2009; Fiebach, Schlesewsky, & Friederici, 2001; Hagiwara, Soshi, Ishihara, & Imanaka, 2007; Matzke, Mai, Nager, Russeler, & Munte, 2002; Muralikrishnan, 2011; Stolterfoht & Bader, 2004; Ueno & Kluender, 2003; Wolff, Schlesewsky, Hirotani, & Bornkessel-Schlesewsky, 2008).

Most studies that investigated the processing of German unambiguous structures agreed that sensitivity to legal case-marking variations manifests very early in the clause, that is, 300–600 ms after the onset of the critical word (Bornkessel et al., 2002b; Fiebach et al., 2001; Matzke et al., 2002; Rösler et al., 1998; Schipke et al., 2012; Schlesewsky et al., 2003). Commonly, the processing of complex syntax has been associated with increasing costs, as reflected by a negative deflection with a variety of distribution patterns across experiments.

A negative ERP response to case-marking variation was observed at various points of the syntactic structure, including fronted/topicalized objects as well as medial-clause objects in main and subordinate clauses. For example, in the experiments by Matzke et al. (2002) that focused on declarative sentences, unambiguously marked topicalized objects in (5.1a) elicited a left frontal negativity between 400–600 ms, as compared to the unambiguously marked subjects in (5.1b). An earlier anterior negative effect (100–400 ms) was reported in an experiment in which adults were exposed to similar structures without an active task (Schipke et al., 2012).

(5.1a) *Den begabten Sänger entdeckte der talentierte Gitarrist.*
the.ACC gifted singer discovered the.NOM talented guitar player
'The talented guitar player discovered the gifted singer.'

(5.1b) *Der begabte Sänger entdeckte den talentierten Gitarristen.*
the.NOM gifted singer discovered the.ACC talented guitar player
'The gifted singer discovered the talented guitar player.'

Left anterior negativities between 300–450 ms were found by studies that assessed scrambling in medial-clause position, that is, at the determiner of the first noun phrase in sentences in (5.2), as compared to their subject-first counterparts (Rösler et al., 1998; Schlesewsky et al., 2003).

(5.2a) *Dann hat dem Sohn der Vater den Schnuller gegeben.*
then AUX the.DAT son the.NOM father the.ACC pacifier give
'Then the father gave the pacifier to the son.'

(5.2b) *Dann hat den Schnuller der Vater dem Sohn gegeben.*
then AUX the.ACC pacifier the.NOM father the.DAT son give
'Then the father gave the pacifier to the son.'

Finally, similar negativities were obtained in complement clauses (Bornkessel et al., 2002b; Bornkessel, Schlesewsky, & Friederici, 2003a; Fiebach et al., 2001). For example, Bornkessel et al. (2002b) compared the processing of subject-first sentences (5.3c) to object-first clauses that contained accusative- (5.3a) and dative-marked (5.3b) topicalized constituents. Accusative-marked objects elicited a centrally distributed negativity between 300–450 ms after the onset of the first NP in the complement clause.

(5.3a) *Maria hörte, dass <u>den Jäger</u> der Gärtner besucht.*
Maria heard that the.ACC hunter the.NOM visits
'Maria heard that the hunter visits the gardener.'

(5.3b) *Maria hörte, dass <u>dem Jäger</u> der Gärtner hilft.*
Maria heard that the.DAT hunter the.NOM gardener helps
'Maria heard that the gardener helps the hunter.'

(5.3c) *Maria hörte, dass <u>der Jäger</u> den Gärtner besucht.*
Maria heard that the.NOM hunter the.ACC gardener visits
'Maria heard that the hunter visits the gardener.'

However, not all fronted objects elicited a negative response. The processing of dative-marked topicalized arguments, as in (5.3b), was not associated with increasing costs in the study by Bornkessel et al. (2002b). Similarly, fronted pronominal arguments did not show such a negativity in the study by Schlesewsky et al. (2003). No effect of word order at the first NP was observed in the study by Frisch et al. (2002) that investigated the differences between syntactically ambiguous and syntactically unambiguous sentences. These findings contributed to the discussion of the functional nature of the early negative deflection. Electrophysiological differences between OVS and SVO constructions were hypothesized to reflect one of two processes: either the maintaining of working memory load associated with storing of the object in the memory until it is integrated (Felser, Clahsen, & Munte, 2003; Fiebach et al., 2001; Fiebach, Schlesewsky, & Friederici, 2002; Matzke et al., 2002); or a grammaticality-based parsing principle (Bornkessel & Schlesewsky, 2006; Bornkessel et al., 2002b; Schipke et al., 2012; Wolff et al., 2008). The latter may be based on the relational properties of the argument in general (Bornkessel-Schlesewsky & Schlesewsky, 2009a; Wolff et al., 2008) or/and on the correspondence of the upcoming argument to the expected syntactic function (Schipke et al., 2012).

Based on the variety of distributional patterns and syntactic contexts, Bornkessel-Schlesewsky and Schlesewsky (2009a) distinguished between two types of negative effects. A sustained left anterior negativity (sLAN) at clause-initial position (Fiebach et al., 2002; Matzke et al., 2002), was related to increasing working memory load. A centrally-distributed negativity, elicited at the medial-clause position (Bornkessel et al., 2002b; Schlesewsky et al., 2003), was termed *scrambling negativity* and related to the mismatch between semantic, syntactic and pragmatic features of the argument and its position in sentence (Bornkessel, Zysset, Friederici, von Cramon, & Schlesewsky, 2005; Grewe et al., 2005). Similarly to this account, a partly anterior negative response that was elicited at clause-initial position in a recent study by Schipke et al. (2012), was attributed to the parsing principle that expects a subject in sentence-initial position. Based on its elicitation point and distribution, the effect was termed *topicalization negativity* (Schipke et al., 2012).

The further sentence analysis depends on the processes that are required by the syntactic context. In the following, two types of such contexts are discussed: complex sentences with unambiguous case marking that require reordering and/or integration of the arguments; and sentences that require reanalysis to resolve local ambiguities induced by case variation.

In complex unambiguously marked sentences, the processing of the second argument or the final verb was reported to involve no additional efforts in several studies (Friederici, Steinhauer, Mecklinger, & Meyer, 1998; Frisch et al., 2002; Knoeferle, Habets, Crocker, & Munte, 2008; Schipke et al., 2012). For example, no differences were detected between the processing of declarative OVS sentences (5.4a) in comparison to SVO sentences (5.4b) in the experiment with adults by Schipke et al. (2012). Together with the negativity elicited at the fronted object, the absence of effect was argued to support subject-first preference in German speakers.

(5.4a) *Den Frosch küsst <u>der Tiger</u>.*
the.ACC frog kisses the.NOM tiger
‘The tiger kisses the frog.’

(5.4b) *Der Tiger küsst den Frosch.*
the.NOM tiger kisses the.ACC frog
'The tiger kisses the frog.'

In the majority of other studies, a positivity for OVS structures was reported both for main (Frisch & Schlesewsky, 2001, 2005; Knoeferle et al., 2008; Rösler et al., 1998; Wolff et al., 2008) and for complement clauses (Bornkessel, Fiebach, & Friederici, 2004; Fiebach et al., 2001; Friederici, Hahne, et al., 2002)[11]. For example, Fiebach et al. (2001) showed a broad positive response between 400–700 ms at the second NP in OVS clauses (5.5a), as compared to SVO clauses (5.5b). This positivity was not affected by individual working memory abilities of subjects. It was classified as P600 and explained linguistically in terms of establishment of the syntactic dependency between gap and filler.

(5.5a) *Thomas fragt sich, wen am Mittwoch der Doktor verständigt hat.*
Thomas asks himself who.ACC on Wednesday the.NOM doctor called has
'Thomas is wondering whom did the doctor call on Wednesday.'

(5.5b) *Thomas fragt sich, wer am Mittwoch den Doktor verständigt hat.*
Thomas asks himself who.NOM on Wednesday the.ACC doctor called has
'Thomas is wondering who called the doctor on Wednesday.'

In this study, P600 was argued to reflect integration difficulty in general, as suggested by Kaan, Harris, Gibson, and Holcomb (2000) and other researchers (Felser et al., 2003; Fiebach et al., 2002; Friederici, Hahne, et al., 2002; Kaan & Swaab, 2003). In a recent combined fMRI-EEG study by Meyer, Obleser, Kiebel, and Friederici (2012), the late left frontal positivity at the subcategorizing final verb of unambiguous OVS sentences, as contrasted with SVO sentences, was correlated to the activity of the inferior frontal gyrus (IFG). These results were attributed to the executive reordering mechanism that operates on the items stored in memory if the encountered argument order does not correspond to the expected order.

An alternative explanation was provided by Bornkessel, Fiebach, et al. (2004) in the study that compared, among others, unambiguously marked OVS comple-

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[11] Negativities observed in the studies of German by Matzke et al. (2002), Rösler et al. (1998) and in the study of Basque by Erdocia et al. (2009) were argued to reflect the retrieval of verbal material in non-canonical position or the storage of displaced elements in memory.

ment clauses to SVO complement clauses (see also Mahlstedt, 2008; Wolff et al., 2008). SVO structures elicited a negative response between 350–500 ms independently of the working memory abilities of the participants. The negativity was argued to reflect a predictability effect induced by the *minimality* principle. When encountering an SVO structure, which theoretically can stop after any constituent, the parser does not initiate preparation for the second argument. In contrast, the OVS structure requires the second argument to be predicted by the processing system. Thus, the analysis of the SVO structure is associated with additional costs at the second NP, as reflected by a negative deflection in response to SVO structures.

A late positivity at around 600 ms was also observed in locally ambiguous sentences that are resolved towards the end of the clause (Bornkessel, McElree, Schlesewsky, & Friederici, 2004; Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001; Friederici et al., 1998; Frisch et al., 2002; Haupt, Schlesewsky, Roehm, Friederici, & Bornkessel-Schlesewsky, 2008; Knoeferle et al., 2008; Matzke et al., 2002). For example, disambiguating the second NP in sentences of type (5.6a) elicited a broad P600, when contrasted to sentences of type (5.6b) in the study by Frisch et al. (2002). The P600 was argued to reflect the revision of the subject-first preference in object-first sentences (Frisch, Graben, & Schlesewsky, 2004; Matzke et al., 2002).

(5.6a) *Die Detektivin hatte der Kommissar gesehen und…*
the.ACC/NOM detective had the.NOM policeman seen and …
‘The policeman saw the detective and…’

(5.6b) *Die Detektivin hatte den Kommissar gesehen und…*
the.NOM/ACC detective had the.ACC policeman seen and…
‘The detective saw the policeman and…’

A similar interpretation was adopted earlier by Mecklinger et al. (1995), who presented participants with the sentences of type (5.7a) and (5.7b), in which the disambiguation of the first NP took place at the final auxiliary of the relative clause. While in (5.7a), the auxiliary directs to the object-first reading, it indicates the subject-first reading in (5.7b):

(5.7a) *Das sind die Professorinnen, die die Studentin gesucht hat.*
these are the.ACC/NOM professors that the.ACC/NOM student looked for has
'These are the professors that the student was looking for.'

(5.7b) *Das sind die Studentinnen, die die Professorin gesucht haben.*
these are the.ACC/NOM students that the.ACC/NOM professor looked for has
'These are the students that looked for the professor.'

The final auxiliary was hypothesized by Mecklinger et al. (1995) to elicit a positive component in object-first relatives due to the mismatch with preferred subject-first reading. In fact, fast comprehenders showed a sharp positivity that occurred between 300–400 ms after auxiliary onset. It was referred to as P345 and interpreted to reflect the need for syntactic reanalysis. This finding was replicated in several studies that investigated the processing of relative clauses (Friederici & Mecklinger, 1996; Friederici et al., 1998; Steinhauer, Mecklinger, Friederici, & Meyer, 1997; Vos, Gunter, Schriefers, & Friederici, 2001). The effect was embedded into the two-stage parsing model (Friederici, 1998). At the first stage, the parser has been claimed to maintain the simplest SVO structure. In case this representation should be revised, two sub-processes take place. The first includes diagnosis for the need of reanalysis, as expressed by an early positivity P345. The second includes the actual reanalysis, reflected by P600. This system was related to individual parsing strategies based on working memory capacities by Vos et al. (2001). In their study, low-span participants, who showed a late frontal positivity, were argued to rely on reordering processes. High-span participants, who showed an early posterior positivity, were hypothesized to rely stronger on their memory.

A non-syntactic interpretation of the early positivity (P345) was suggested by Bornkessel et al. (2002a) (see also Bornkessel et al., 2003b; Leuckefeld, 2005). In contrast to the previous studies, the positive effect was elicited in sentences (5.8), in which local thematic ambiguity was introduced by case marking:

(5.8) *Maria hörte, dass der Professor dem Gärtner gefällt/dankt.*
Maria heard that the.NOM the.DAT gardener pleases/thanks
Maria heard that the professor is pleasing to/thanks the gardener.

Thematic revision was not necessary if the final verb was *dankt* 'thanks' because the verb confirmed the agent-patient relationship maintained pre-verbally. This relationship should have been reanalyzed if the sentences ended with object-experiencer verbs such as *gefällt* 'pleases'. The early positivity elicited at the 'disambiguation' point (*gefällt/dankt*) suggested that positivities described above can be discussed in terms of sentence hierarchical structuring.

To sum up, studies on the processing of syntactic complexity involving case-marking and word order variations in German reported several neurophysiological components in adults. The processing of initial arguments was associated with early negativities, whereas integration/reordering/reanalysis costs at further arguments and subcategorizing verbs were reflected by early and late positivities, depending on structural context.

The processing of case marking in children

Probably the first electrophysiological precursors of dependency processing in sentential context have been shown in infants (Friederici, 2005; Friederici & Männel, 2014). Four-month-old children in the study by Friederici, Mueller, and Oberecker (2011) were able to differentiate between grammatical and ungrammatical dependencies in the sentence. Other studies that used a syntactic violation paradigm demonstrated that children were sensitive to the violations of phrase-structure rules and morphosyntactic categories as early as 24 months of age (Bernal, Dehaene-Lambertz, Millotte, & Christophe, 2010; Oberecker & Friederici, 2006; Oberecker, Friedrich, & Friederici, 2005). The ERP data of 3-year-olds indicates that they detect double-nominative case violations (5.9a) in an adult-like manner, showing an early anterior negative response that is followed by a late positivity (Schipke et al., 2011). In the same study, double-accusative case violations (5.9b) were associated with an early positivity, indicating that the anomaly was detected by 3-year-old children. It did not, however, trigger the process of thematic/syntactic reanalysis, as it was observed in older children and adults.

(5.9a) **Der Tiger küsst* <u>*der Frosch*</u>. (double nominative)
the.NOM tiger kisses the.NOM frog

(5.9b) **Den Tiger küsst* <u>*den Frosch*</u>. (double accusative)
the.ACC tiger kisses the.ACC frog

Based on these findings, Schipke and colleagues suggested that the basic principles of thematic role assignment are established by the age of three. At this stage, children were sensitive to the functional meaning of nominative case and to the multiple use of one case marker in a sentence.

The online processing of syntactic complexity involving case and word order variations by children has been sparsely investigated. Schipke et al. (2012) reported that children at the age of 3;0 were sensitive to the case marking at sentence-initial position, as expressed by a positivity between 700–800 ms for declarative OVS structures in contrast to SVO structures. Based on previous ERP findings on syntactic anomaly, they speculated that 3-year-olds process accusative-marked determiner at NP1 as a violation. Children at this age are not yet able to recognize and interpret the syntactic structure marked by case and rely primarily on positional cues. Children at the age of 4;6 were argued to enter a transitory stage at which they start to recognize the syntactic structure, as indicated by a positivity between 1300–1400 ms at NP2 for OVS sentences and their behavioural response. Finally, children at the age of 6;0 processed complex sentences in an adult-like manner. They showed a topicalization negativity between 300–400 ms at sentence-initial argument, but also two effects at the second NP: an early positivity between 100–200 ms and a late sustained positivity between 600–1700 ms. The late positivity was interpreted as indicating an integration difficulty. The ability of school children to use case marking for sentence interpretation was also shown by Leuckefeld (2005) who presented 11;6-year-old children with unambiguously case-marked sentences. A positive effect between 700–1100 ms for object-experiencer verbs was interpreted as a marker of thematic reanalysis.

Schipke's et al. (2012) findings for 3-year-old children were partly compatible with the data obtained by Mahlstedt (2008) who investigated the processing of case marking and animacy in context of the eADM model. The author observed a negative deflection between 300–500 ms in response to SVO sentences at the animate NP1 in 3;3-year-old children. This result was interpreted as reflecting a better lexical access of the initial nominative-marked animate noun. At the second NP, a biphasic response consisting of an early negativity 220–600 ms and a late positivity 750–1200 ms were found[12]. The late positivity was argued to reflect the general wellformedness-check, as described by the Phase 3 of the eADM model. The effect also indicated children's preference for the accusative-marked argument after a transitive verb in sentence.

To summarize, the sensitivity of German 3-year-old children to case has been marked by two electrophysiological responses. A positive component which is elicited when encountering a non-canonical form in sentence-initial position. Further integration efforts are reflected by the late positivity at the second argument.

Neurophysiological correlates of animacy processing

The processing of animacy in adults

Healthy adults differentiate between living and non-living entities. The neurophysiological reality of this differentiation was established in a number of studies that presented participants with individual words in the visual (Marchenko, 2010; Proverbio, Del Zotto, & Zani, 2007; Sitnikova, West, Kuperberg, & Holcomb, 2006; Verkhlyutov, Mar'ina, & Strelets, 2013) and auditory (Kovic, Plunkett, & Westermann, 2010) modalities. Category-specific semantic effects were found at the latency of the N400, an ERP component associated with semantic processing. The ERP response to inanimates has mostly shown to be more negative during the epoch 300–500 ms (Kovic et al., 2010; Proverbio et al., 2007; Sitnikova et al., 2006). Distinct spatial distributions of effects elicited by animates and inanimates (Sitnikova et al., 2006) indicated that they were at least partially mediated by different brain regions. This finding was in line with brain imaging data (but cf. Gerlach, 2007; A. Martin, 2007).

Animacy has been shown to have an effect on sentence processing in adults across languages, including German (Frisch & Schlesewsky, 2001; Roehm et al.,

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[12] Effects at NP2 were reported as an early positivity and late negativity for accusative-marked argument in *Der Tiger kauft* <u>*den Hut*</u> [the.NOM tiger is buying the.ACC hat] as compared to nominative-marked argument *Den Hut kauft* <u>*der Tiger*</u> [the.ACC hat is buying the.NOM tiger].

2004), English (Nakano, Saron, & Swaab, 2010; Weckerly & Kutas, 1999), Korean (Y. Lee, Kwon, & Gordon, 2014), Russian (Stoops, Luke, & Christianson, 2014), Mandarin Chinese (Li, Zhao, Zheng, & Yang, 2014; Philipp, Bornkessel-Schlesewsky, Bisang, & Schlesewsky, 2008; Wang, 2011), Dutch (Kos, Vosse, van den Brink, & Hagoort, 2010), Spanish (Nieuwland, Martin, & Carreiras, 2013). However, there has been no agreement as to how the effects of animacy manifest during sentence comprehension.

In the neurocognitive model of auditory sentence processing (Friederici, 1995, 2002), the processing of semantic features and assignment of thematic roles take place in the second phase, right after the word category is recognized. These processes are reflected by the N400, as evidenced by a large body of literature that investigated ERP responses to semantic anomalies (e.g., Friederici & Frisch, 2000; Friederici, Pfeifer, & Hahne, 1993; Rösler, Putz, Friederici, & Hahne, 1993). Such anomalies were often realized as violations of verb selectional restrictions that involve, among other features, the violation of the animacy of an expected argument. For example, both violations (5.10a) and (5.10b) elicited an N400 relative to their controls in experiments by Friederici and Frisch (2000).

(5.10a) *Anna weiß, dass der Kommissar den Banker <u>abbeizte</u> und wegging.*
Anna knows that the.NOM inspector the.ACC banker stained and left
'Anna knows that the inspector stained the banker and left'.

(5.10b) *Heute beizte der Cousin <u>den Geiger</u> am Mittag.*
today stained the.NOM cousin the.ACC violinist at noon
'The cousin stained the violinist today at noon'.

In addition, in the structure NP – NP – Verb (5.10a) a late positivity P600 was observed. It was interpreted as reflecting integration of syntactic and semantic information. Based on fMRI and MEG studies, processes associated with the N400 were linked to the middle and posterior parts of superior temporal gyrus (e.g., Friederici, Ruschemeyer, Hahne, & Fiebach, 2003).

However, N400 was not elicited in some studies that investigated animacy-related thematic violations. Instead, only P600 and sometimes a biphasic pattern of N400/P600 were observed in several experiments (Hoeks, Stowe, & Doedens, 2004; Kim & Osterhout, 2005; Kolk, Chwilla, van Herten, & Oor, 2003;

Kuperberg, Sitnikova, Caplan, & Holcomb, 2003; van Herten, Chwilla, & Kolk, 2006). For example, Hoeks et al. (2004) reported a P600, but not an N400 effect in animacy-violated sentences (5.11a) relative to (5.11b).

(5.11a) *De speer heeft de atleten geworpen.*
the javelin has the athletes thrown
'The javelin threw the athletes.'

(5.11b) *De speer werd door de atleten geworpen.*
the javelin was by the athletes thrown
'The javelin was thrown by athletes.'

Hoeks et al. (2004) suggested that participants were following a semantically plausible version of the sentence for a few hundred milliseconds until it was in conflict with the syntactic interpretation. That is, for a short period of time, semantic processing might have been in control of sentence comprehension. P600 signalled the attempt to resolve the *illusion* induced by the semantic processing stream.

A similar line of interpretation could be found in the work by Kim and Osterhout (2005) who observed an N400 only in sentences with low semantic attraction between verb and argument (5.12a), as compared to passive control (5.12c).

(5.12a) *The dusty tabletops were devouring.* (low semantic attraction)

(5.12b) *The hearty meal was devouring the kids.* (high semantic attraction)

(5.12c) *The hearty meal was devoured by the kids.* (control)

In sentences with high semantic attraction (5.12b), the P600 was elicited at the verb in contrast to control sentences. Both low and high semantic attraction stimuli contained an animacy violation: *meal was devouring* and *tabletops were devouring*. Thus, animacy of the first NP could not account for the differences in ERP patterns. Authors concluded that the semantic relationship between the noun and the verb guided participants during sentence comprehension. Having relied strongly on the semantic relationship between the constituents, they perceived a grammatically correct sentence as agrammatical structure. This process was reflected by the P600.

In contrast to Kim and Osterhout (2005) and Hoeks et al. (2004) who assumed a two-stream language processing, Kuperberg (2007) suggested that language comprehension follows even more streams (for a review, see Brouwer, Fitz, & Hoeks, 2012; Brouwer & Hoeks, 2013; van de Meerendonk, Kolk, Chwilla, & Vissers, 2009). Semantic memory-based stream is sensitive to semantic features and associative relations between words. The computations related to this stream are reflected by the N400. The second, combinatorial stream, is sensitive to morphosyntactic constraints on one hand, and to semantic-thematic constraints including animacy, on the other hand. The P600 was claimed to reflect a *continued* updating and reanalysis of the combinatorial stream. This reanalysis was triggered by the conflict between the output of the semantic memory-based stream and anomalous interpretation produced by the combinatorial stream. Kuperberg et al. (2003) investigated two types of semantic violations: animacy-based thematic violation (5.13a) and world-knowledge/pragmatic violation (5.13b) (see also Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006).

(5.13a) *For breakfast the eggs would only eat toast and jam.* (animacy violation)
(5.13b) *For breakfast the eggs would only burry toast and jam.* (pragmatic violation)

Animacy-based thematic violations elicited a relatively small N400 and a P600 response, whereas world-knowledge violations were associated with an N400. P600 was taken to reflect the conflict between expected and assigned thematic role as well as costs of thematic reassignment.

In a series of experiments with German sentences, the N400 was argued to reflect the problems of thematic interpretation. In the experiment by Schlesewsky and Bornkessel-Schlesewsky (2009), in which complement clauses of type (5.14a) were contrasted with plausible clauses (5.14b), an N400 and a P600 were elicited at the categorizing verb.

(5.14a) *... dass der Schalter den Techniker bedient.*
… that the.NOM switch the.ACC technician operates
'… that the switch operates the technician.'

(5.14b) *... dass den Schlater der Techniker bedient.*
… that the.ACC switch the.NOM technician operates
'… that the technician operates the switch.'

Here, N400 was interpreted as reflecting a conflict between the contradicting cues of animacy and case marking. The impact of animacy on the incremental processing of sentence arguments was discussed within the eADM model (Bornkessel & Schlesewsky, 2006). The model suggests that sentence processing follows two streams. The thematic stream computes the thematic role of the argument on the basis of prominence scale that includes case marking, argument order, animacy, definiteness, person information. Thematic roles are linked to the argument positions of the verb. The plausibility processing stream combines the categories on the basis of their lexical-semantic associations. Difficulties that are encountered during the processing in any of these two streams are reflected by the N400. Conflicts that are encountered during the integration of two streams are reflected by a P600. The P600 may be also associated with problems that occur during the final "well-formedness" evaluation of the utterance.

In line with this model, Schlesewsky and Bornkessel-Schlesewsky (2009), argued that the N400 reflects the conflict that occurred during thematic processing. Similarly, in Schlesewsky and Bornkessel (2004) sentences (5.15a) elicited an N400 at NP2 in contrast to (5.15b). Thematic processing of NP1 was claimed to introduce an expectation of the ideal Actor. Since the expectation was not fulfilled due to the inanimate status of NP2, the conflict occurred.

(5.15a) ... *welchen Mönch der Zweig streifte.*
… which.ACC monk the.NOM twig brushed
'.. which monk the twig brushed.'

(5.15b) ... *welchen Mönch der Bischof begleitete.*
… which.ACC monk the.NOM bishop accompanied
'… which monk the bishop accompanied.'

Thus, according to the findings of these experiments and other supporting studies (Frisch & Schlesewsky, 2001; Grewe et al., 2007; Grewe et al., 2005, 2006; Röhm, Klimesch, Haider, & Doppelmayr, 2001), animacy and thematic role interpretation are closely related. Mismatches induced by relational animacy are mostly associated with the N400 component in German.

In all, N400 and P600 were suggested as two main ERP markers of animacy during sentence processing. The emergence of these components was related to the processing in either syntactic, semantic or thematic streams. Recently, a new

Retrieval-Integration (RI) account was proposed by Brouwer et al. (2012) (see also Brouwer & Hoeks, 2013). The RI account is a single-stream model that interprets the N400 as reflecting long-term memory retrieval that includes syntactic, semantic and pragmatic information associated with a certain word. The P600 was argued to reflect the integration of the activated information into a current mental representation of the ongoing sentence. The absence of an N400 in some studies was attributed to the effect of word and context priming. The model predicts that 1) the amplitude of the N400 is not associated with plausibility violations, 2) the amplitude of the P600 is related to integration difficulty and increases at clause boundaries, and 3) the amplitude of the P600 depends on task demands (Brouwer et al., 2012).

The processing of animacy in children

Neurophysiological evidence of animate-inanimate differentiation was found in infants at the age of 4–7 months (Elsner, Jeschonek, & Pauen, 2013; Jeschonek, Marinovic, Hoehl, Elsner, & Pauen, 2010; Pauen & Höhl, 2011). These studies used randomized and oddball visual paradigms, in which the words from two categories were presented without sentential context.

The effects of animacy on sentence interpretation were only sparsely investigated in children. For example, Hahne, Eckstein, and Friederici (2004) explored the ERP signatures of sematic violations in children between ages of 6 and 13. These violations included, but were not limited to, animacy violations, such as *Das Lineal wurde gefüttert.* 'The straight edge was fed'. Semantic anomalies elicited an N400 pattern. The latency of the N400 decreased with age.

Integration efforts associated with semantic processing were also observed in 19- and 24-month-old children (Friedrich & Friederici, 2005b). In a series of experiments children were presented with simple SVO sentences, in which object nouns violated selection restrictions of the verbs, e.g., *The cat drinks the ball.* The observed long-lasting centro-parietal negativity at the NP2 indicated that the children attempted to semantically integrate the verb and the object. This study and further experiments using semantic anomalies (Silva-Pereyra, Klarman, Lin,

& Kuhl, 2005; Silva-Pereyra, Rivera-Gaxiola, & Kuhl, 2005) showed that semantic integration mechanisms are present in children at around the age of two.

To our knowledge, only one study explicitly investigated the impact of animacy on the interpretation of syntactically complex sentences in preschool German-speaking children (Mahlstedt, 2008). The study focused on the supportive use of animacy in two types of sentences. The processing of subordinate clauses with a final verb (*Mama sagt, dass den Ball der Clown schubst*. 'Mom says that the.ACC ball the.NOM clown pushes') was not associated with a thematic-related N400 either at NP2 or at the verb, as it was shown for adults. These results suggested that children did not use semantic information to interpret object-first subordinate clauses. The importance of the 'canonical' transitive template with animate-before-inanimate order was confirmed.

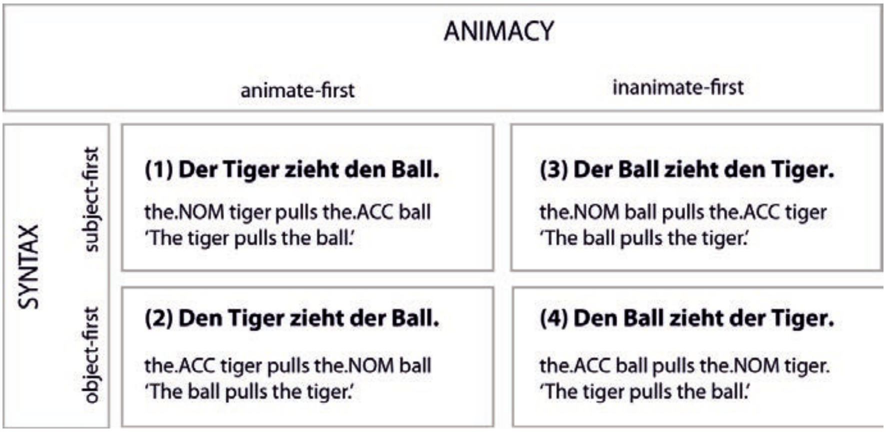
Mahlstedt (2008) also investigated the processing of main clauses, such as *Den Hut kauft der Doktor*. 'The.ACC hat buys the.NOM doctor'. In OVS inanimate-first sentences, a marginally significant positivity between 600–900 ms was found. This effect was interpreted as reflecting thematic reanalysis of the first inanimate actor towards the patient role. This indicates that children were able to use cooperating cues of animacy and case in main declarative clauses. Other ERP effects observed in this experiment pointed to children's preference of 'canonical' transitive sentence template.

Despite a large body of behavioral research on the use of semantic and syntactic cues for sentence interpretation in preschool children (for details, see review in Chapter 4.1), only few experimental studies focused on the neurophysiological nature of relational use of animacy in early childhood. The present study aims to contribute to this field by investigating the brain activity associated with the processing of syntactic and semantic cues in small children.

Current study

The major objective of the current ERP study was to assess the neurophysiological correlates of children's case marking and animacy processing at the age of 2 and 3 years. The results of the picture-matching task showed that both age groups attended to the semantic cue during sentence interpretation. Two-year-olds were able to use animacy only in simple SVO sentences, in which it was cooperating with other features such as nominative case marking and sentence-initial position. In contrast, 3-year-olds were able to correctly respond to the OVS sentences with cooperating cues of case marking and animacy. On the other hand, 3-year-olds were also able to ignore the plausibility violation introduced by inanimate nouns in sentence-initial position if word order and nominative case marking were cooperating.

A two-by-two experimental design was employed to investigate the ERP correlates of this behaviour. A passive listening paradigm was chosen for this experiment, since the accomplishment of an active comprehension task appeared to be restricted in 2- and 3-year-olds during EEG measurement. To date, a passive listening paradigm is the most common method to study sentence processing in very young children (Friedrich & Friederici, 2005b; Schipke et al., 2011; Schipke et al., 2012; Silva-Pereyra, Klarman, et al., 2005; Silva-Pereyra, Rivera-Gaxiola, et al., 2005).



		ANIMACY	
		animate-first	inanimate-first
SYNTAX	subject-first	**(1) Der Tiger zieht den Ball.** the.NOM tiger pulls the.ACC ball 'The tiger pulls the ball.'	**(3) Der Ball zieht den Tiger.** the.NOM ball pulls the.ACC tiger 'The ball pulls the tiger.'
	object-first	**(2) Den Tiger zieht der Ball.** the.ACC tiger pulls the.NOM ball 'The ball pulls the tiger.'	**(4) Den Ball zieht der Tiger.** the.ACC ball pulls the.NOM tiger. 'The tiger pulls the ball.'

Figure 5.1.1. Design of the ERP experiment.

The study manipulated syntactic and semantic cues. Similar to the behavioural picture-matching task, syntactic manipulation was realized via nominative and accusative case marking yielding SVO and OVS sentences (Figure 5.1.1). Based on the linear processing of sentence constituents in the ERP experiment, semantic contrast was realized via the animate and inanimate status of individual nouns.

Thus, due to the absence of a functional task, the semantic feature of the noun, but not the semantic feature of the agent, was in focus of the ERP study.

SVO and OVS sentences without animacy contrast, that is, with two animate NPs, were also presented during the ERP experiment. However, they were not analyzed due to the fact that neither one of the age groups showed an above-chance performance in complex structures.

5.2 Experiment 3a: 2-year-olds

Experiment 3a aimed to investigate the processing of syntactic and semantic cues by 2-year-old children from a neurophysiological perspective. Taking into account children's performance in the behavioral task, our youngest participants were expected to focus their efforts on the interpretation of simple SVO sentences with cooperating positional and semantic cues such as *Der Tiger schiebt den Schrank.* 'The.NOM tiger pulls the.ACC wardrobe'.

There were five critical points in stimulus sentences: Determiner 1, Noun 1, Verb, Determiner 2 and Noun 2. First, 2-year-old children were expected to differentiate between nominative and accusative case marking at Determiner 1. This sensitivity should not be necessarily reflected by a *topicalization* negativity at the determiner itself, since the accusative case marker at the beginning of the sentence does not appear to signal syntactic complexity and trigger memory-related processes in small children. Rather, a later discriminative response was expected at Noun 1, as it was observed in 3-year-old children by Schipke et al. (2012). In their study, no effects of syntax were found at the second NP. Thus, two-year-olds were hypothesized to show

- sensitivity to case marking at NP1, as reflected by a positive response to OVS structures (Mahlstedt, 2008; Schipke et al., 2012);
- no further cognitive efforts associated with the processing of case marking at NP2 (Schipke et al., 2012).

In terms of semantics, the main prerequisite to the understanding of such sentences is the differentiation between animates and inanimates *per se*. The impact of animacy on relational interpretation might be observed at two points. First, the processing of the inanimate in a sentence-initial position in SVO structures might lead to increasing processing costs at Noun 1 due to the conflict between the semantic cue and the positional cue/nominative case marker. Second, increased processing costs are expected at the verb in SVO sentences with initial inanimate nouns due to semantic integration difficulties. Thus, the following effects and interactions involving animacy were expected:

- main effects of animacy indicating category processing differences at content words (Noun 1 and Noun 2);
- semantic effects in SVO sentences at Noun 1, indicating the disconfirmation of expectancies about semantic features of the first argument in prototypical sentences;
- semantic effects in SVO sentences at the Verb, as reflected by a negative response to inanimate-first relative to animate-first sentences, triggered by verb-restriction violation (Friedrich & Friederici, 2005b; Silva-Pereyra, Klarman, et al., 2005).

Methods

Participants

Ninety-six 2-year-old children between the age of 24–35 months participated in the study. Informed parental consent was obtained for all children before the experiment. EEG recording was not possible in seven children. The data of six 2-year-olds was excluded due to various reasons, including the neurological or hearing disease history (5) and bilingual environment (1). The data on language abilities was collected using TSVK (Siegmüller et al., 2010) during a separate experimental session. One child did not participate in this test. Parents completed the vocabulary and grammar subcomponents of the questionnaire FRAKIS (Szagun et al., 2009) (for details of these measurements, see the description of participants sample in Chapter 4.2). Eleven children performed below norm level in one of the FRAKIS subtests; the data of additional three children was not available. Twenty of the two-year-old children did not provide enough EEG data, that is, at least 15 artefact-free trials for each condition. The final data set consisted of EEG recordings of 48 two-year-old children (age range 24−35 months, M_{age} = 29 months, *SD* = 3.41 months, 24 girls). Table 5.2.1 summarizes the data on language development of children that were included in the final analysis. As can be seen from the normed scores, the linguistic abilities of all children corresponded to the norms established for their age.

Table 5.2.1. Results of the language development diagnostics in the final data sample in Experiment 3a.

Test	**Raw score (n = 48)**			**Normed score (n = 48)**		
	Mean	Range	SD	Mean	Range	SD
TSVK argument structure	6.23	2–10	1.89	59.35	41–76	8.43
FRAKIS vocabulary	80.96	13–107	24.04	65.92	18–96	27.82
FRAKIS word forms	38.33	2–71	17.08	68.08	18–96	26.72
FRAKIS sentence complexity	19.94	2–32	9.11	56.08	18–96	25.93

Note. TSVK, Test zum Satzverstehen von Kindern (Siegmüller et al., 2010). FRAKIS, Fragebogen zur frühkindlichen Sprachentwicklung (Szagun et al., 2009).

Materials

To explore the relevance of syntactic and semantic cues for sentence interpretation in adults and children, we created 180 German simple transitive sentences of a structure [NP – V – NP]. Six animate nouns, six inanimate nouns and 12 verbs were chosen on the basis of language test SETK-2 (H. Grimm et al., 2000), CHILDES corpus (MacWhinney, 2000) and previous literature (Schipke, 2012). These nouns were: *der Hund* ‘the dog’, *der Esel* ‘the donkey’, *der Vogel* ‘the bird’, *der Fuchs* ‘the fox’, *der Igel* ‘the hedgehog’, *der Tiger* ‘the tiger’, *der Keks* ‘the biscuit’, *der Kuchen* ‘the cake’, *der Schrank* ‘the wardrobe’, *der Topf* ‘the pot’, *der Turm* ‘the tower’. The verbs were: *schieben* ‘to push’, *ziehen* ‘to pull’, *werfen* ‘to throw’, *beißen* ‘to bite’, *hauen* ‘to hit’, *treten* ‘to kick’, *kneifen* ‘to pinch’, *heben* ‘to lift’, *fangen* ‘to catch’, *kratzen* ‘to scratch’, *tragen* ‘to carry’, *schlagen* ‘to beat’. Both sentence arguments were expressed by strong masculine nouns. These formed accusative without an additional suffix or vowel change. Thus, case-marking information in the sentences was available only on the determiners. The stimuli were balanced in such way that each referent equally often took the agent/patient role and equally often appeared together with each verb. The sentences were computer-randomized using the `conan` tool (Nowagk, 1998), so that neither a syntactic nor a semantic structure appeared more than three times consecutively. The occurrence of the lexical items in a certain sentence position was constrained, e.g., an object or an animal was not repeated at NP1 position in three subsequent trials. Ten randomization lists were generated in this manner.

The experimental material was recorded by a trained female speaker in a child-directed manner. The offline editing included inserting a 50-ms silence period at the beginning and the end of each sentence as well as a RMS normalization of speech amplitude using MATLAB scripts (The MathWorks, Inc., Natick, MA, USA).

Procedure

The procedure was very similar to that of the EEG experiments on auditory discrimination between the determiners *der* and *den* (for details, see *Procedure*, Chapter 3.2). It included a short warm-up and debriefing session. Prior to the EEG experiment, animals and objects were introduced to the children. Children were presented with the images of animals/objects one at a time and asked to name them. The experimenter corrected the answer if the name was inaccurate.

The EEG experiment was conducted in an electrically-shielded cabin. Children were seated on their parent's lap in front of the VGA/CRT monitor. The display of the monitor was partly covered by a black-colored paper frame leaving an 29×22 cm window. A silent cartoon film "Fantasia" (Armstrong, 2002) was shown to prevent excessive motion in the 2-year-olds. The film consisted of the scenes that did not have a coherent story. Children were asked to carefully listen to the sentences and try to remember who was doing what to whom so that they could play a puzzle game after the experiment. No other comprehension task was conducted during the EEG session.

Stimulus sentences were presented aurally via Bowers & Wilkins loudspeakers (B&W Group Germany GmbH, Halle, Germany) with an interstimulus interval (stimulus offset to stimulus onset) of 2500 ms. Parents were instructed to wear ear plugs and avoid communicating with the child. The experiment was divided into two blocks of 90 sentences. Each block had a duration of approximately 10 minutes. The cabin was constantly observed via a built-in video camera, and additional breaks were made if necessary.

EEG recording

The parameters of the EEG measurements were the same as in the experiments on auditory discrimination (for details, see *EEG recording*, Chapter 3.2).

Data analysis

Electrophysiological data was pre-processed using the same algorithms of artefact correction and rejection as in the experiments on auditory discrimination (for details, see *Data analysis*, Chapter 3.2). Epochs, time-locked to the onset of five sentence constituents (Determiner 1, Noun 1, Verb, Determiner 2, Noun 2) were extracted. The length of the epoch for the determiners was 500 ms. The length of noun and verb epochs was 1000 ms. Due to the absence of a condition-independent time period suitable for each constituent, no pre-stimulus baseline was used (Friederici et al., 2000; Royle & Courteau, 2013). Only sentences that were completely free of artefacts were included into the individual ERPs. Thus, the number of trials for all sentence constituents was kept equal for all ERP comparisons.

Statistical analyses were performed using PASW Statistics 22 (SPSS, Inc) on mean amplitudes in consecutive windows of 50 ms. The number of time windows (TWs) depended on the length of the sentence constituent. Both determiners were analyzed using 10 TWs between 0–500 ms (e.g., 0–50 ms, 50–100 ms, 100–150 ms, etc). Noun 1, Noun 2 and the verb were analyzed in 20 TWs between 0–1000 ms. Nine regions of interest (ROIs) were defined in anterior-posterior and lateral planes: anterior-left (AL), anterior-middle (AM), anterior-right (AR), central-left (CL), central-middle (CM), central-right (CR), posterior-left (PL), posterior-middle (PM), posterior-right (PR).

The impact of syntactic and semantic cues on sentence processing was tested using a repeated measures ANOVA with factors Syntax [subject-first; object-first], Animacy [animate-first; inanimate-first], AP [anterior; central; posterior] and LP [left; middle; right]. Interactions involving the factor of Syntax and

Animacy were analyzed after visual inspection of ERP waves. Corrections using the Greenhouse-Geisser method were applied if the assumption of sphericity was violated, as indicated by the Mauchly's test of sphericity (Greenhouse & Geisser, 1959). Effects were considered to be reliable if they were confirmed in at least two neighboring time windows. Voltage topographies were computed using mean amplitudes between the first and the last time window with reliable effects.

Results

First noun phrase

The accusative-marked article did not elicit a reliable negative brain response when compared to nominative-marked article (Figure 5.2.1, left panel).

At the first noun, OVS sentences elicited an early positive response that started soon after the onset of the noun (50–200 ms, Figure 5.2.1, right panel). This effect was confirmed by ANOVA that revealed the main effect of syntax between 100–200 ms (Table 5.2.2). In several TWs, interactions with distributional factors were found. Analysis of Syntax × LP interaction in T 50–100 ms confirmed the left-focused distribution of effect. Analysis of Syntax × AP interactions between 100–200 ms showed that the differences between subject and object-first sentences were significant in anterior and central areas.

Table 5.2.2. Syntax effects as calculated at Noun 1 in 2-year-old children.

TW	**Main effect of syntax** *F***(1, 47)**	**Syntax × AP (df) F**	**Syntax × AP Resolved**			**Syntax × LP (df) F**	**Syntax × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
50–100						(2, 94) 3.76*	6.38*	-	-
100–150	8.25**	(1.28, 60.14) 4.59*	9.96**	7.21**	-				
150–200	4.99*	(1.23, 57.59) 4.02*	7.96**	-	-	(1.66, 78.06) 3.51*	7.71**	5.13*	-

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, midline; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*.

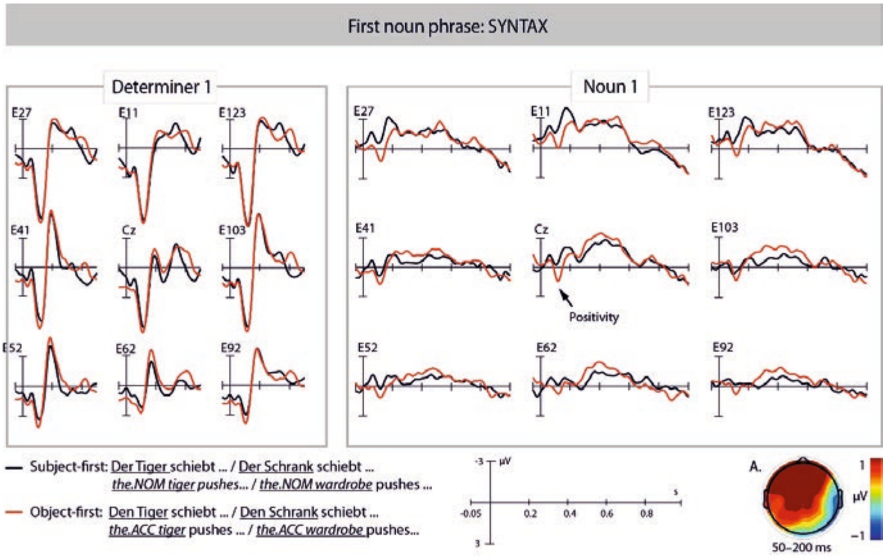


Figure 5.2.1. ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of Determiner 1 (left panel) and Noun 1 (right panel) elicited in 2-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Noun 1, as calculated at object-first minus subject-first difference wave between 50–200 ms.

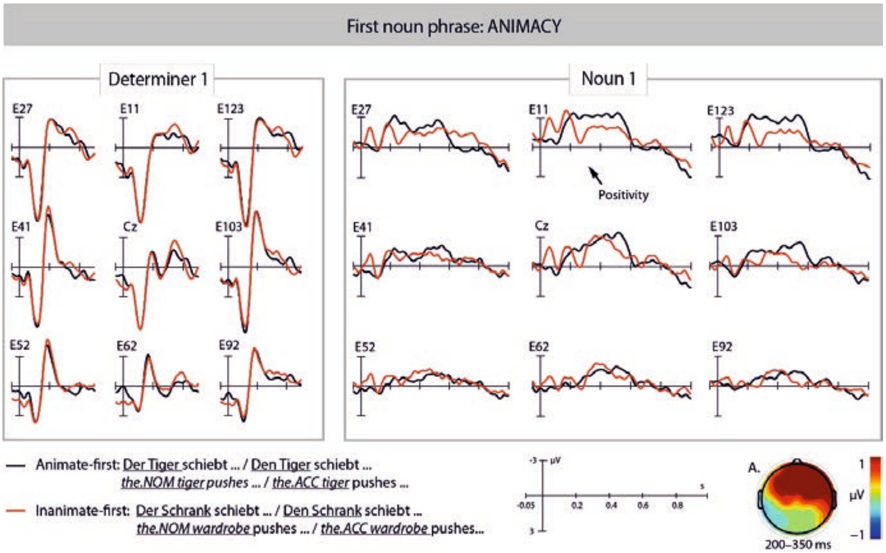


Figure 5.2.2. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 1 (left panel) and Noun 1 (right panel) elicited in 2-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Noun 1, as calculated at inanimate-first minus animate-first difference wave between 200–350 ms.

As expected, determiners did not elicit any effects related to animacy (Figure 5.2.2, left panel). The processing of inanimate noun, as compared to the animate noun, was associated with a positive deflection between 200–600 ms at anterior electrode sites and two short positivities at central and posterior electrode sites (Figure 5.2.2, right panel).

ANOVA revealed the main effects of animacy in successive TWs 200–250 ms (*F*(1, 47) = 3.15, *p* = .082), 250–300 ms, as well as 500–550 ms (Table 5.2.3). Interactions with distributional factor AP in TWs 200–350 ms were resolved showing a primarily anterior-central response pattern. Interaction with distributional factor LP in TW 250–300 ms did not show area-specific pattern.

Table 5.2.3. Animacy effects as calculated at Noun 1 in 2-year-old children.

TW	**Main effect of animacy** ***F*(1, 47)**	**Animacy × AP (df) F**	**Animacy × AP Resolved**			**Animacy × LP (df) F**	**Animacy × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
200–250	3.15^{m}	(1.46, 68.69) 4.56*	5.53*	-	-				
250–300	15.82**	(1.35, 63.23) 6.08**	15.09**	11.68**	4.09*	(1.73, 81.15) 4.23*	7.48**	16.66**	14.55**
300–350		(1.42, 66.75) 4.65*	5.32*	-	-				

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, midline; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*, .05 < p < .1^{m}.

In a number of TWs, the analysis revealed syntactic complexity with animacy interactions. There were Syntax × Animacy × AP interactions between 0–100 ms and 300–400 ms, Syntax × Animacy × LP interaction between 100–150 ms, Syntax × Animacy interactions between 400–600 ms as well as Syntax × Animacy × AP × LP interaction in TW 400–450 ms (*F*(3.09, 145.14) = 3.13, *p* = .026, Table 5.2.5). As can be seen in Figure 5.2.3, ERP response to the semantic manipulation in SVO sentences differed from the response in OVS sentences. In SVO condition, animate-inanimate contrast elicited a positivity between 400–600 ms that was distributed over all scalp areas. In OVS condition, the pattern was more complex. A somewhat earlier positivity (200–400 ms) was observed anteriorly. It co-occurred with a negative deflection that could be found at posterior electrode sites between 300–500 ms.

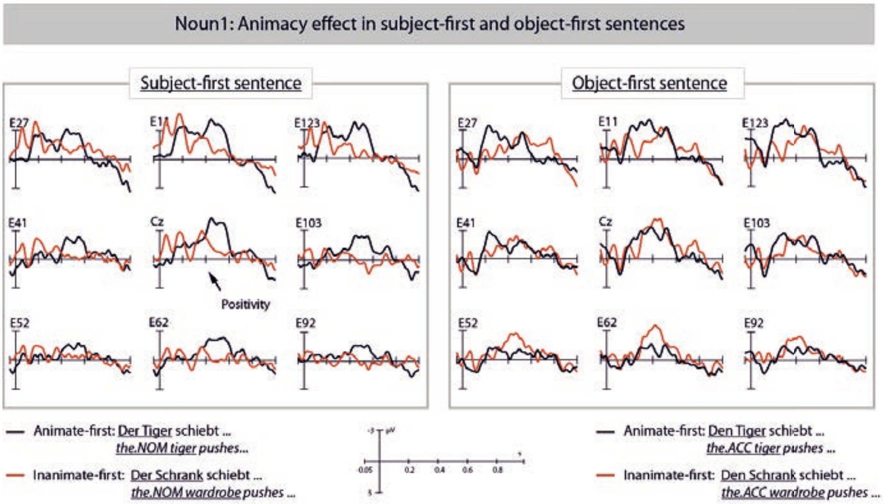


Figure 5.2.3. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Noun 1 in subject-first (left panel) and object-first (right panel) sentences elicited in 2-year-old children. Negativity is plotted upwards.

Table 5.2.4. Animacy effects as calculated at Noun 1 in 2-year-old children for subject-first and object-first sentences.

TW	Interaction	(df) F	Animacy effects	
			Subject-first	Object-first
0–50	S × A × AP	(1.29, 60.68) 4.60*	A: 4.50*	-
50–100	S × A × AP	(1.39, 65.27) 6.85**	A: 6.46* A × AP: (1.18, 55.59) 9.15** → ANT: 11.29** → CENT: 6.12*	-
100–150	S × A × LP	(2, 94) 3.55*	-	-
300–350	S × A × AP	(1.51, 71.04) 4.09*	-	A × AP: (1.46, 68.65) 8.94** → ANT: 8.68**
350–400	S × A × AP	(1.58, 74.10) 6.61**	-	A × AP: (1.33, 62.32) 8.63** → ANT: 5.40*
400–450	S × A S × A × AP × LP	(1, 47) 8.69** (3.09, 145.14) 3.13*	A: 6.02* A: 6.04*	- A × AP: (1.21, 56.78) 4.67* → POST: 8.12**
450–500	S × A	(1, 47) 21.01**	A: 15.51**	-
500–550	S × A	(1, 47) 7.71**	A: 14.12**	-
550–600	S × A	(1, 47) 3.41*	A: 7.62**	-

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, middle; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*, .05 < p < .1^{m}.

Separate analyses of syntactic conditions showed reliable effects of animacy in time intervals 0–100 ms and 400–600 ms in SVO but not in OVS sentences (Table 5.2.4). The analysis of Animacy × AP interaction in TW 50–100 ms showed an anterior and central distribution of this effect. In OVS condition, the positive deflection was statistically confirmed between 300–400 ms. It was mostly pronounced in anterior areas.

Verb

The brain responses to OVS versus SVO sentences are represented in the left panel of Figure 5.2.4. They do not differ considerably. In contrast, the ERP responses to inanimate-first and animate-first conditions (Figure 5.2.4, right panel) showed a broadly-distributed early effect that started before the verb onset and extended up to approximately 200 ms later. Furthermore, there was a late animacy effect around 700 ms at the right electrode sites.

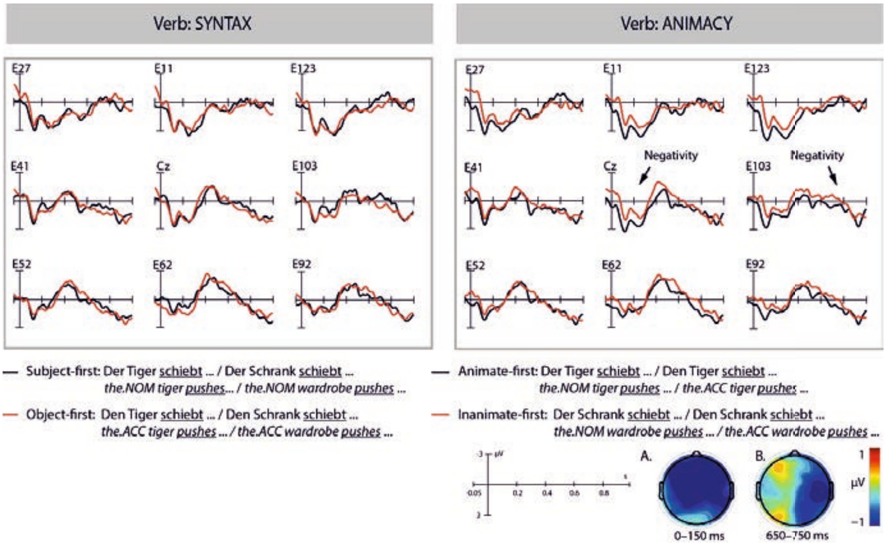


Figure 5.2.4. Left panel: ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of the verb. Right panel: ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of the verb elicited in 2-year-old children. Negativity is plotted upwards. A: Voltage topography of the first negativity at the verb, as calculated at inanimate-first minus animate-first difference wave between 0–150 ms. B. Voltage topography of the first negativity at the verb, as calculated at inanimate-first minus animate-first difference wave between 650–750 ms.

The animacy effects were confirmed by the ANOVA. The main effect was observed between 0–150 ms (Table 5.2.5). The late negativity for inanimate-first sentences was confirmed via Animacy × LP interactions in TWs 650–700 ms and

700–750 ms. The analysis of these interactions showed that the effect was at largest at the right electrode sites.

Table 5.2.5. Animacy effects as calculated at Verb in 2-year-old children.

TW	Main effect of animacy $F(1, 47)$	Animacy × LP (df) F	Animacy × LP Resolved		
			LEFT	MID	RIGHT
0–50	4.86*				
50–100	10.80**				
100–150	5.08*				
650–700		(1.57, 73.65) 4.10*	-	-	5.91*
700–750		(1.69, 79.46) 4.33*	-	-	5.95*

Note. TW, time window; LP, lateral plane. Specific areas: LEFT, left; MID, midline; RIGHT, right. $p \leq .01$**, $.01 < p \leq .05$*, $.05 < p < .1^{m}$.

Finally, the processing of syntax was modulated by animacy in time intervals between 100–250 ms (Table 5.2.6). It is clear from Figure 5.2.5 that this interaction was guided by animacy differences in SVO sentences. The ERP response to inanimate-first condition showed a greater negative deflection in SVO than in OVS sentences.

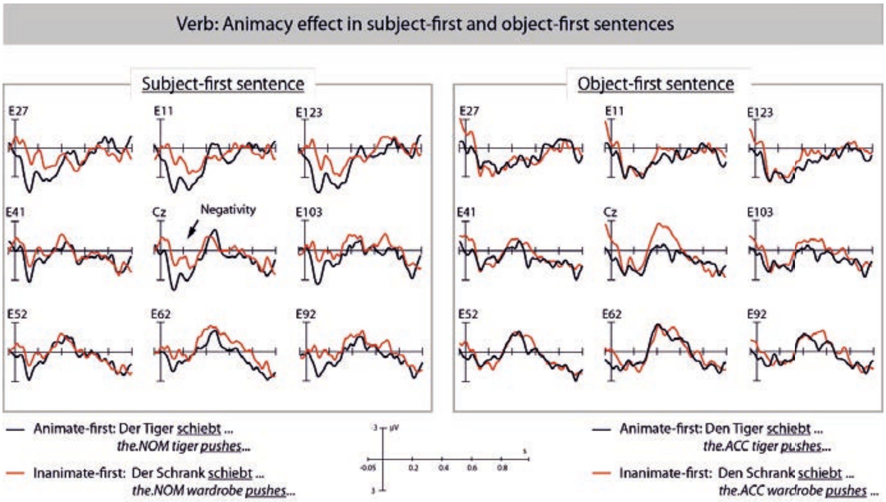


Figure 5.2.5. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of the verb in subject-first (left panel) and object-first (right panel) sentences elicited in 2-year-old children. Negativity is plotted upwards.

In the animate versus inanimate analysis for SVO sentences, reliable effects of animacy were found for this time interval (Table 5.2.6). For the animate versus inanimate analysis for OVS sentences, no significant effects were found.

Table 5.2.6. Animacy effects as calculated at the verb in 2-year-old children for subject-first and object-first sentences.

TW	**Interaction**	***F*(1, 47)**	**Animacy effects**	
			Subject-first	**Object-first**
100–150	S × A	6.39*	11.49**	-
150–200	S × A	3.35^{m}	4.37*	-
200–250	S × A	4.27*	4.11*	-

Note. S, factor Syntax; A, factor Animacy. $p \leq .01$**, $.01 < p \leq .05$*, $.05 < p < .1^{m}$.

Second noun phrase

Figure 5.2.6 shows the ERP responses related to the processing of NP2. At the determiner, OVS sentences elicited a positivity that could be primarily observed at anterior electrode sites (Figure 5.2.6, left panel). At the noun, a biphasic pattern consisting of an early negativity (approximately 0–300 ms), as well as of a late positivity (around 600 ms) could be observed (Figure 5.2.6, right panel).

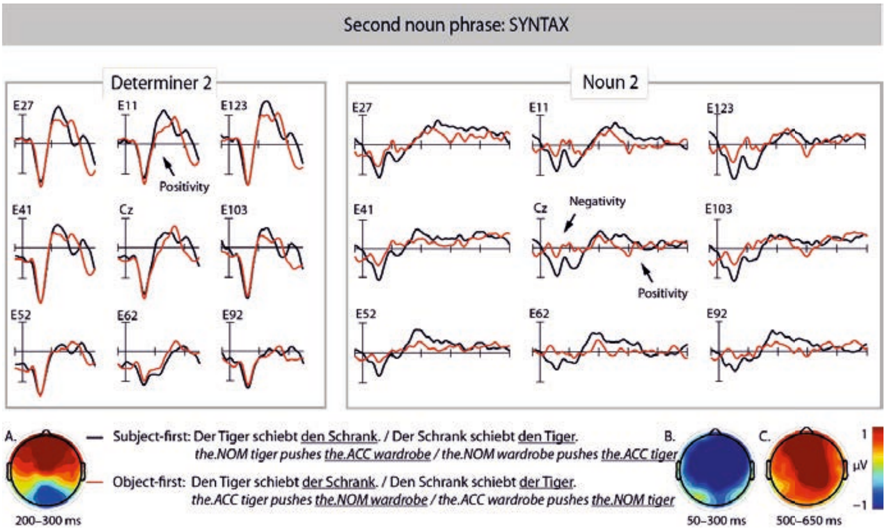


Figure 5.2.6. ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of Determiner 2 (left panel) and Noun 2 (right panel) elicited in 2-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Determiner 2, as calculated at object-first minus subject-first difference wave between 200–300 ms. B. Voltage topography of the negativity at Noun 1, as calculated at object-first minus subject-first difference wave between 50–300 ms. C. Voltage topography of the positivity at Noun 1, as calculated at object-first minus subject-first difference wave between 500–650 ms.

Statistical analysis of the ERP responses supported these observations. Differences between OVS and SVO sentences at the determiner were confirmed via Syntax × AP interactions in TWs 200–250 ms and 250–300 ms (Table 5.2.7). In TW 200–250 ms, there was a three-way interaction Syntax × AP × LP (*F*(3.22, 151.38) = 5.12, *p* = .002). Syntax effects were distributed in all anterior (left: *F*(1, 47) = 4.67, *p* = .036; middle: (*F*(1, 47) = 5.66, *p* = .021; right: *F*(1, 47) = 4.04, *p* = .05) and central middle (*F*(1, 47) = 5.68, *p* = .021) regions of interest.

At the noun, a main effect of syntax was found in a series of TWs between 50–250 ms (Table 5.2.7). At a later latency (200–250 ms), the effect was present in anterior and central areas, as evidenced by the analysis of the two-way interaction Syntax × AP. The negativity had the greatest duration at the right electrode sites, as confirmed by a Syntax × LP interaction in TW 250–300 ms (*F*(2, 94) = 2.98, *p* = .056). The late positivity at the second noun reached significance in TWs between 500–650 ms.

Table 5.2.7. Syntax effects as calculated at NP2 in 2-year-old children.

TW	**Main effect of syntax *F*(1, 47)**	**Syntax × AP (df) F**	**Syntax × AP Resolved**			**Syntax × LP (df) F**	**Syntax × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
Second determiner									
200–250		(1.30, 61.05) 6.54**	5.17*	-	-				
250–300		(1.28, 60.27) 5.53*	5.44*	-	-				
400–450	15.97**	(1.27, 59.43) 7.70**	15.13**	18.50**	-				
450–500	4.79*	(1.27, 59.57) 8.83**	10.32**	5.14*	-				
Second noun									
50–100	4.48*								
100–150	7.72**								
150–200	4.24*								
200–250	10.12**	(1.24, 58.43) 4.16*	8.15**	10.71**	-				
250–300						(2, 94) 2.98^{m}	-	-	5.01*
500–550	7.85**								
550–600	9.13**								
600–650	4.28*								

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, midline; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*, .05 < p < $.1^{m}$.

The ERP contrast between inanimate-first and animate-first sentences at the second noun phrase is represented in Figure 5.2.7. Inanimate-first structures elicited a positive response at the determiner around 300 ms. The processing of the noun resulted in a complex pattern consisting of a positivity (approx. 0–200 ms), a negativity (approx. 350–550 ms) and a positivity (approx. 600–100 ms) for the inanimate-first sentences. The pattern was mostly evident in anterior areas.

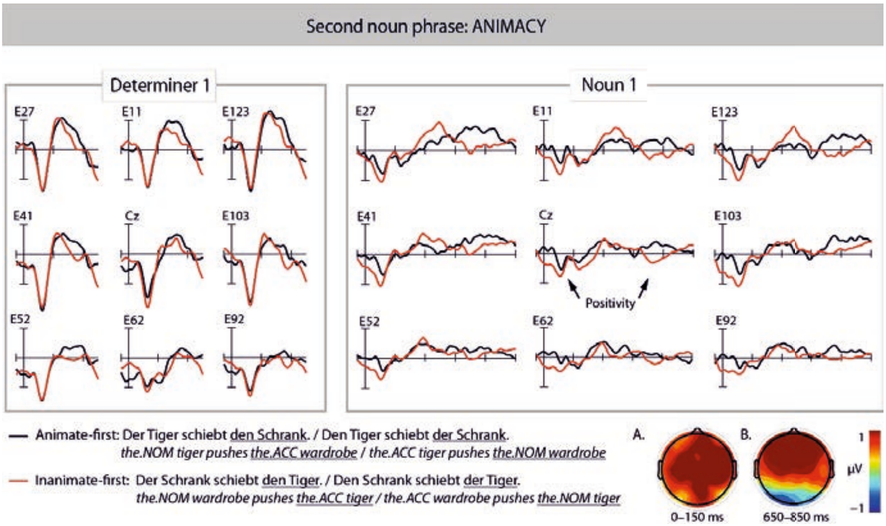


Figure 5.2.7. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 2 (left panel) and Noun 2 (right panel) elicited in 2-year-old children. Negativity is plotted upwards. A: Voltage topography of the first positivity at Noun 2, as calculated at inanimate-first minus animate-first difference wave between 0–150 ms. B. Voltage topography of the second positivity at Noun 2, as calculated at inanimate-first minus animate-first difference wave between 650–850 ms.

Statistical analyses partly confirmed these observations. At the determiner, the animacy effect was significant in one TW 350–400 ms ($F(1, 47) = 4.83$, $p = .033$). At the noun, the first positivity reached significance in time period between the word onset and 150 ms, as evidenced by animacy main effects in corresponding time windows (Table 5.2.8). The second positivity did not reach significance in at least two neighboring TWs. The effect had an anterior distribution, but was significant only in one TW 450–500 ms ($F(1, 47) = 7.29$, $p = .010$). The third deflection was confirmed statistically for the time period 650–850 ms. In the corresponding TWs, the main effect of animacy and interactions with distributional factor AP were found. Analysis of two-way interactions confirmed the anterior-central distribution of the late animacy effect.

Table 5.2.8. Animacy effects as calculated at Noun 2 in 2-year-old children.

TW	Main effect of animacy $F(1, 47)$	Animacy × AP (df) F	Animacy × AP Resolved		
			ANT	CENT	POST
0–50	7.38**				
50–100	18.12**				
100–150	5.54*				
400–450		(1.55, 72.75) 4.56*	-	-	-
450–500		(1.48, 69.73) 12.98**	7.29**	-	-
500–550		(1.50, 70.37) 9.58**	-	-	9.45**
650–700	3.89^{m}	(1.42, 66.72) 2.92^{m}	5.23*	-	-
700–750	13.14**	(1.53, 71.79) 6.82**	12.93**	14.27**	-
750–800	8.68**	(1.57, 73.80) 3.94*	8.08**	10.89**	-
800–850	5.91*	(1.40, 65.94) 5.47*	10.10**	5.75*	-
850–900		(1.30, 61.11) 3.76*	-	-	-

Note. TW, time window; AP, anterior-posterior plane. Specific areas: ANT, anterior; CENT, central; POST, posterior. $p \leq .01$**, $.01 < p \leq .05$*, $.05 < p < .1^{m}$.

Finally, four-way interactions Syntax × Animacy × AP × LP were found at the second determiner in TWs between 200–450 ms (Fs = 2.67–6.28, p = .000217–.047, Table 5.2.9). As can be seen in Figure 5.2.8, the distribution of syntactic positivity between 200–300 ms differed slightly in animate-first and inanimate-first sentences. This was confirmed by separate ANOVAs that tested the factor of syntax in two semantic conditions.

In animate-first sentences, the effect of syntax, as reflected by a positivity, was found in anterior areas via Syntax × AP interactions in TWs 200–250 ms and 250–300 ms. Follow-up analyses revealed anterior distribution of the effect in both TWs (200–250 ms: $F(1, 47) = 3.95$, $p = .053$; 250–300 ms: $F(1, 47) = 5.64$, $p = .022$). In inanimate-first sentences, the effect of syntax was reliable only in central-middle ROI between 200–250 ms.

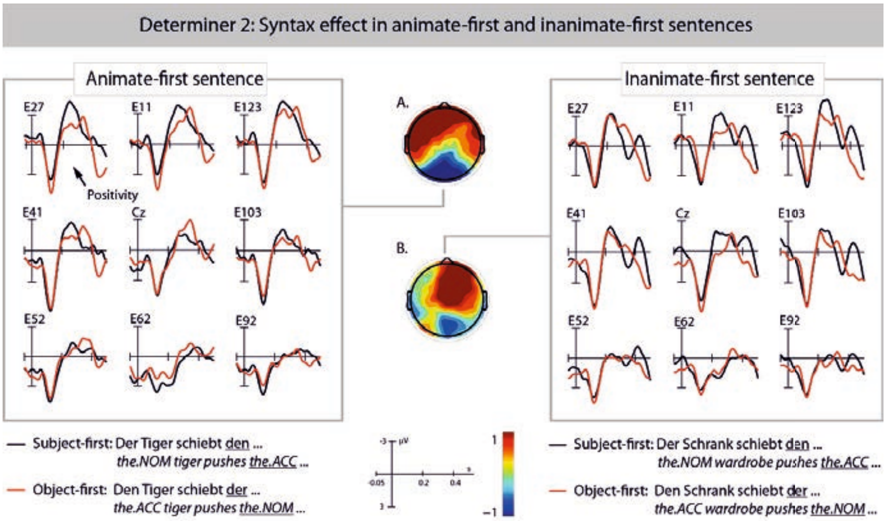


Figure 5.2.8. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 2 in subject-first (left panel) and object-first (right panel) elicited in 2-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Determiner 2, as calculated at object-first minus subject-first difference wave between 200–300 ms in animate-first sentences. B: Voltage topography of the positivity at Determiner 2, as calculated at object-first minus subject-first difference wave between 200–300 ms in inanimate-first sentences.

Table 5.2.9. Syntax effects as calculated at Determiner 2 in 2-year-old children for animate-first and inanimate-first sentences.

TW	Interaction (df) F	Syntax effects	
		Animate-first	**Inanimate-first**
200–250	(4, 188) 3.29*	S × AP: (1.41, 66.31) 4.87* → ANT: 3.95^{m}	S × AP × LP: (3.35, 157.57) 7.14** → CM: 5.78*
250–300	(3.18, 149.53) 3.67*	S × AP: (1.26, 59.21) 4.27* → ANT: 5.64*	S × AP × LP: (2.70, 127.04) 3.54* → No effects
300–350	(3.15, 148.18) 2.67*	-	-
350–400	(4, 188) 6.28**	S × AP × LP: (3.13, 147.19) 2.72* → No effects	S × AP × LP: (2.82, 132.34) 3.93** → No effects
400–450	(3.28, 154.04) 5.86**	S 4.29* S × AP × LP: (3.17, 149.20) 3.48* → AL**, CL*	S: 16.68** S × AP: (1.22, 57.45) 8.15** → ANT*, CENT*, POST* S × AP × LP: (2.93, 137.94) 2.74* → AL** AM** AR** CL** CM** CR**[13]

Note. S, factor Syntax; A, factor Animacy. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; p ≤ .01**, .01 < p ≤ .05*, .05 < p < .1^{m}.

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[13] Syntax effects observed in time window 400–450 ms were not found in neighboring windows and were not further investigated.

To sum up, OVS sentences elicited a positive response at the second determiner between 200–300 ms. This syntax effect was also modulated by the semantic factor showing different distributional patterns in animate-first and inanimate-first sentences. At the second noun, the processing of syntactically complex structure was associated with a biphasic pattern consisting of a negativity (50–250 ms) and a positivity (500–650 ms). The semantic manipulation evoked two positivities at the second noun.

Discussion

The current ERP experiment aimed at investigating the online processing of syntactic and semantic interpretative cues by 2-year-old children. Table 5.2.10 summarizes the effects that were observed in the ERP data.

Table 5.2.10. Summary of the main ERP findings in 2-year-old children.

Factor	**Determiner 1**	**Noun 1**	**Verb**	**Determiner 2**	**Noun 2**
Syntax	-	Positivity 50–200 ms	-	Positivity 200–300 ms	Negativity 50–250 ms Positivity 500–650 ms
Animacy	-	Positivity 200–350 ms	Negativity 0–150 ms Negativity 650–750 ms	-	Positivity 0–150 ms Positivity 650–900 ms
Interaction	-	0–600 ms → animacy effect in subject-first	100–250 ms → animacy effect in subject-first	200–300 ms → syntax effect in animate-first	-

Note. Syntactic effects are indicated for object-first sentences relative to subject-first sentences; semantic effects are indicated for inanimate-first sentences relative to animate-first sentences.

Syntactic cues

In line with previous research on the processing of complex syntactic structures in preschool children (Mahlstedt, 2008; Schipke et al., 2012), our participants did not show a 'topicalization' negativity at the first determiner. However, a more positive brain response to an unexpected determiner *den* at sentence-initial position could be observed at the first noun. Due to the very early onset of the positivity (50 ms), when time-locked to the noun, and the absence of a baseline prior to the noun, we assume that this effect was triggered by the differences in sentence-initial determiners *der* and *den*. This agrees with data collected in 3-

year-old children (Mahlstedt, 2008; Schipke et al., 2012) and indicates that even younger children are sensitive to case marking at the beginning of the sentence.

Following Schipke's argumentation, the positive shift might be interpreted as a reaction to morphosyntactic violation. This explanation is in line with ERP data on the processing of syntactic anomalies in 24-month-old (Bernal et al., 2010; Oberecker & Friederici, 2006), 30-month-old (Silva-Pereyra, Klarman, et al., 2005), 36-month-old and 48-month-old (Silva-Pereyra, Rivera-Gaxiola, et al., 2005) children. In studies by Silva-Pereyra and colleagues, the violation of verb forms in sentential context was associated with late positive (in 30-month-olds) as well as early and late positive (in 36- and 48-month-olds) ERP responses. Twenty-four-month old children showed a long-lasting positivity starting at 350 ms as a reaction to word category violation in French (Bernal et al., 2010). German-speaking children at this age showed an early (100–300 ms) and a late positivity (1100–1700 ms) in response to phrase structure violations. Therefore, the positivity obtained at the first noun of OVS sentences suggests that sentence-initial non-nominative determiner might be interpreted as a morphosyntactic violation.

The processing of OVS sentences elicited an unexpected positivity at the second determiner (200–300 ms). The effect of syntactic complexity was modulated by animacy of the sentence-initial argument. The positivity was significant in anterior areas in animate-first sentences, but not in inanimate-first sentences. In other words, the impact of syntactic complexity was enhanced when the preverbal position was occupied by an animate noun. There are several possible explanations for these results.

The effect might be triggered by purely acoustic differences between *der* and *den*, as it was found in our previous study on the acoustic processing of these determiners without sentential context. However, the analysis of word duration, intensity and fundamental frequency showed that only one parameter could confound with the processing of determiner and produce similar effects. Namely, intensity minimum, as measured at the second determiner, interacted with animacy of the first argument. This parameter showed greater differences in animate-first sentences (approx. 5 dB) than in inanimate-first sentences (approx. 1 dB).

However, a similar relationship between conditions was observed at the first noun itself. It was not related to the processing of syntax (for details, see Appendix C). Thus, acoustic differences alone cannot account for the positive response to object-first sentences at the second determiner.

The other possibility is that the positivity is related to the processing of the syntactic/thematic structure by 2-year-olds. Both our behavioural study and previous literature (e.g., Dittmar et al., 2008) indicate that children at this age are able to understand prototypical SVO structures, in which syntactic cue of case marking cooperates with positional and semantic cues. It is therefore possible that children are also able to maintain expectancies about the upcoming thematic/grammatical structure, e.g., about non-nominative case form and the ideal patient in the sentence-final position. ERP data on case violations reported by Schipke et al. (2011) confirmed this idea for 3-year-old children. In their study, the violated case form of the second determiner in sentences of type (5.16a) elicited an adult-like negativity-positivity pattern, when contrasted with grammatically correct SVO structures (5.16b).

(5.16a) **Der Tiger küsst* *der Frosch.*
The.NOM tiger kisses the.NOM frog

(5.16b) *Der Tiger küsst* *den Frosch*.
The.NOM tiger kisses the.ACC frog
'The tiger kisses the frog'.

The effect was not observed in more complex double-accusative violations, in which an early positivity at NP2 was found. The results indicated that SVO but not in OVS sentences. The study showed that the basic principle of thematic role assignment (i.e., the principle that each thematic role is assigned once in sentence) has been established by the age of three. It is therefore not unreasonable to suggest that the positivity obtained at the second determiner in 2-year-old children in the current study can be attributed to the mismatch between their expectation of the non-agentive role/non-nominative form and the determiner *der* at this position. The positivity thus might reflect the detection of a syntactic "anomaly" (Silva-Pereyra, Rivera-Gaxiola, et al., 2005) or the problem of thematic hierarchizing (Bornkessel et al., 2002a).

Early positive effects at the terminal position of syntactically complex sentences were observed in adult data. Rösler et al. (1998) attributed such positivity to the revision of syntactic frame and role allocation schemata. Wolff et al. (2008) argued the effect was triggered by the resolution of dependency. Mecklinger et al. (1995) attributed the short lasting positivity P345 to the mismatch between initially selected interpretation and perceived structure (see also Friederici & Mecklinger, 1996). It was claimed to reflect the process of diagnosis in locally ambiguous sentences. Vos et al. (2001) related the early positivity obtained in high span readers to the early recovering from being garden-pathed by object-relative clause. Finally, Bornkessel et al. (2002a, 2003b) suggested that the early positivity can be explained by non-syntactic factors. The effect was argued to reflect the reversal of thematic roles triggered by the processing of the final verb that forced a thematic reinterpretation of actor and patient roles in sentence. Similar effects were reported by Leuckefeld (2005) who tested 11-year-old children and found a corresponding positivity between 700–1000 ms.

Taken together, these findings indicate that the early positivity reflects a recomputation process in adults. If this applies to young children, a strong explanation might suggest that 2-year-old children are able to launch such recomputation process. As evidenced by the interaction of syntax with animacy at NP1, this effect is stronger in sentences, in which other cues, such as animacy and word order, are cooperating. The conflict between animacy and position in inanimate-first sentences appears to intervene with syntactic processing in 2-year-olds. However, it is evident that the suggested recomputation process occurring in 2-year-old children is not sufficient to produce a correct behavioural response.

In the current data, OVS sentences elicited an early negative response at the second noun (50–250 ms), as compared to SVO sentences. That means that determiner *den* in NP2 was associated with a positive component. The symmetrical ERP pattern related to the determiner *den* at both argument positions speaks in favour of non-syntactic explanation of children's sensitivity to the differences between the two determiners. In addition to the natural differences in the vowel and final consonant, the determiners diverged in overall word duration. Acoustic analyses of stimulus materials showed that *den* was in average 10 ms longer than *der* in both NPs (for details, see Appendix C). Similar duration discrepancies and positive ERP effects associated with *den* were reported by Mahlstedt (2008) and Schipke (2012). Therefore, although possible syntactic violations might contribute to the accusative-related positivities at the nouns, these can also be explained by non-syntactic factors. In all, these results suggest that grammatical information provided by the determiner *den* is not used for thematic/syntactic assignment.

Our syntactic manipulation also elicited a late positivity at the second noun for OVS sentences. These results are in agreement with the data obtained by Mahlstedt (2008) in 3;3-year-old children. A late P600-like component was also found at NP2 by Schipke et al. (2012) in 4;6-year-old children. The positivity in the current study did not show a P600-specific posterior distribution and will be referred to as a late positive component. In adults, late positivities were elicited by sentences with syntactic violations (Osterhout & Mobley, 1995) as well sentences that require reanalysis and reordering (Fiebach et al., 2001, 2002; Friederici et al., 2001; Kaan et al., 2000; Meyer et al., 2012). Late positivities have been reported in 2-year-old children as a response to phrase structure violations, such as **Der Löwe im brüllt* 'The lion in is roaring' (Oberecker & Friederici, 2006; Oberecker et al., 2005). Broadly distributed late positive shift was also observed in the data of 30-month-old children by Silva-Pereyra, Klarman, et al. (2005) who presented children with verb form violations. Together with the above discussed data, our results might indicate that the late positive component reflects children's attempt to functionally interpret the recomputed structure at the end of the sentence.

Semantic cues

Animacy had an impact on the processing of syntax in 2-year-old children. An inanimate first noun evoked a positivity between 200–350 ms. A similar positivity for the semantic factor was previously described for 3-year-old children (Mahlstedt, 2008). Although it differs from some adult studies that manipulated noun semantics and showed more negative response for inanimates in sentence-initial position (Bornkessel & Schlesewsky, 2006; Meltzer & Braun, 2013; Nakano et al., 2010; Weckerly & Kutas, 1999), it is consistent with the positivity elicited by inanimate nouns in the semantic priming paradigm by Hata, Homae, and Hagiwara (2013). Thus, the positive effect at the first noun might reflect pure category discrimination. This result indicates incremental processing of semantic features during sentence comprehension.

Another possible explanation of the animacy effect might be related to the probability of occurrence of the first inanimate argument in the experimental context. Since sentences of all six conditions were presented in randomized order and no filler sentences were used, inanimate nouns appeared at the sentence beginning in only 1/3 of the experimental items. Due to their low proportion, such sentences might cause surprise, attention shift and produce an early positivity P300 (Čeponienė et al., 2004; Hruby & Marsalek, 2003; Picton, 1992). P300 is closely related to disconfirmation of an expectation about an upcoming event (Van Petten & Luka, 2012). Infrequent stimuli elicit a larger positive deflection than frequent stimuli. In the current study, the occurrence of inanimates in sentence-initial position was not completely balanced. The positive effect between 200–350 ms thus might be explained as a reaction to the unexpected semantic feature at the beginning of the sentence. This explanation, however, does not contradict the fact that our participants were sensitive to semantic manipulation.

Moreover, the processing of semantic differences was affected by syntactic structure in the current experiment. It required more cognitive costs at <u>the first noun</u> in SVO than in OVS sentences. Several thematic cues, including argument position, case marking and animacy, are competing at this position. In terms of the eADM model, the interaction at the first NP reflects a thematic conflict introduced by different prominence scales. On the one hand, the effect of animacy at NP1 might be due to children's preference for the animate entity in sentence-initial position. In other words, the positivity has been triggered by the mismatch between the roles assigned by a positional cue (the first encountered argument encodes an agent) and an animacy cue (animate noun encodes an agent). However, if the conflict was induced solely by these cues, a similar effect would occur in object-first sentences. This was not the case in the current data.

More plausibly, the positive deflection at the noun in *Der Schrank...* 'The.NOM wardrobe…' in comparison to *Der Tiger…*'The.NOM tiger' reflects a thematic mismatch induced by the grammatical cue of case marking (nominative form encodes an agent) and animacy (animate noun encodes an agent). Experimental and corpus-based studies indicate that nominative is the first form in the acquisition path of German case system (Clahsen, 1984; Meisel, 1986; Tracy, 1986). Our behavioral study showed that children correctly interpreted sentences in which nominative case form was cooperating with other cues. Taken together, these findings indicate that the functional meaning of nominative case marking may be established by the age of two.

The negativity for inanimate-first sentences at the verb indicates the ongoing processing efforts related to animate-before-inanimate preference and integration of the noun and verb semantics. This effect has an early onset between 100–250 ms. Previous studies that investigated semantic processing using picture-word paradigm with 14-, 19- and 24-month-old children showed similar early negative effects for congruous picture-word pairs (Friedrich & Friederici, 2004, 2005a). The early onset of the negativity was explained by lexical-phonological priming that was triggered by picture context and thus facilitated the processing of a congruous word. Lexical expectations might cause a similar early effect in the current study. Since the thematic role of the first argument is not yet recognized by the child on the basis of the accusative case marker, the presence of the inanimate noun in sentence-initial position always triggers a semantic problem in the present experimental setup. That is, both in (5.17a) and (5.17b), the inanimate noun predicts a subsequent verb-restriction violation in the current experimental conditions. This expectation might facilitate the processing of semantic anomaly in SVO sentences.

(5.17a) *Der Schrank beißt…*
The.NOM wardrobe bites…

(5.17b) *Den Schrank beißt…*
The.ACC wardrobe bites…

Independently of case marking, children's response to the verbs following inanimate nouns was more negative than that to the verbs following an animate noun and reached significance between 650–750 ms. The late negative effect of animacy was consistent both with the data on the processing of single-word semantic incongruences (Friedrich & Friederici, 2004, 2005a) and semantic anomalies in sentential contexts (Friedrich & Friederici, 2005b; Silva-Pereyra, Klarman, et al., 2005). Thus, the late negativity to the inanimate-first sentences at the verb appeared to reflect the difficulty of semantic integration between the verb and anomalous argument.

Finally, semantic manipulation elicited an early (0–150 ms) and a late (450–900 ms) positive responses at the second noun. The early positive effect can partly be attributed to the perceptual differences at the onset of the noun. Specifically, the intensity level at the onset of the inanimate noun was significantly higher than intensity at the onset of the animate noun (55.56 dB versus 51.46 dB; for details, see Appendix C). Similar sensitivity to the physical feature of intensity was observed by Oberecker et al. (2005) in 24-month-old children who showed an early positive response (100–300 ms) to syntactically anomalous sentences that were confounded with intensity discrepancies at the onset of the critical word. In addition, the early positivity can reflect a categorization effect that was facilitated by semantic expectation. This was due to the fact that the second argument of the inanimate-first sentences was always animate, whereas the second argument of the animate-first sentences was either animate (50% of cases) or inanimate (50% of cases).

Inanimate-first sentences triggered increased processing costs at the second noun in comparison to animate-first sentences, as evidenced by the late positive component. A similar finding was reported for 3-year-old children by Mahlstedt (2008). It was attributed to the processing of lexical differences between animate and inanimate nouns. Sabisch, Hahne, Glass, von Suchodoletz, and Friederici (2006) observed a late positive effect in 9-year-old healthy children as well as children with language specific impairment in response to sentence *Der Vulcan wurde gegessen.* ‘The volcano was eaten.’ relative to *Das Brot wurde gegessen.* ‘The bread was eaten’. The effect was argued to reflect processes related to sentential judgment. Since no task was used in the current study, we speculate that the late positivity at the second noun reflects incremental discrimination between semantic categories.

To summarize, the ERP data of 2-year-old children indicate that they are sensitive to the accusative-marked determiner in sentence-initial position but are not yet able to functionally interpret it. They appear to follow the interpretation of only simple SVO structures and perhaps maintain expectations about the upcoming grammatical features of these structures. Already at the age of two, children appear to be able to launch repair processes if such syntactic expectations are not fulfilled.

Obviously, 2-year-olds discriminate between animate and inanimate entities in a sentential context. Does animacy have impact on sentence processing? On the one hand, children expect an animate noun in coalition with the nominative case marking. The processing of inanimate NP1 triggers additional cognitive efforts on integrating the semantic features of this noun and the verb. These processes take place in simple SVO structures. On the other hand, the effect of animacy extends to the second determiner, showing that cooperation of the semantic cue with word order facilitates potential recomputation of syntactic/thematic structure in 2-year-olds. Thus, the current ERP data provides initial evidence for the suggestion that a semantic cue facilitates interpretation of complex structure in very young children. The experiments indicate that 2-year-olds are aware of case marking as a cue for the assignment of thematic roles but only the nominative case form is functionally acquired by this age.

5.3 Experiment 3b: 3-year-olds

Experiment 3b aimed at investigating the processing of syntactic and semantic cues in 3-year-old children. The picture-matching experiment showed that along with the SVO structures, they were able to correctly respond to OVS structures such as *Den Schrank schiebt der Tiger.* ‘The tiger pulls the wardrobe’. Based on this data, we assumed that 3-year-olds did not completely acquired the functional meaning of the accusative case marking, but were able to use the animacy contrast to perform well in sentences in which the grammatical cue was cooperating with the semantic one. Thus, semantic features of the argument facilitated the processing of syntactically complex sentences.

In adults, the contradicting thematic roles assigned by animacy and case marking were shown to elicit an “prototypicality” N400 component in German (Bornkessel-Schlesewsky & Schlesewsky, 2014b; Frisch & Schlesewsky, 2001; Schlesewsky & Bornkessel-Schlesewsky, 2009). Our behavioral experiment demonstrated that 3-year-old children may be sensitive to such conflicts. In fact, sentences such as *Den Tiger beißt der Schrank.* ‘The.ACC tiger bites the.NOM wardrobe’ were responded to with the worst accuracy. The ERP experiment intended to examine the neurophysiological correlates of this behavior.

As in Experiment 3a with 2-year-old children, five critical positions in sentence were examined. These included Determiner 1, Noun 1, Verb, Determiner 2 and Noun 2. In terms of syntactic cues, 3-year-olds were hypothesized to show

- no negative effect of syntax at Determiner 1 due to the lacking ability to maintain sentence syntactic/thematic structure based on the first determiner;
- sensitivity to case marking at Noun 1 and Noun 2, as reflected by a positive deflection in response to article *den* (Mahlstedt, 2008; Schipke et al., 2012);
- either a positive response to syntactically complex structure (in line with 2-year-olds’ data) or no effect at Determiner 2 (Schipke et al., 2012).

Our semantic manipulation was expected to elicit

- category discrimination effects at Noun 1 and Noun 2, as observed in 2-year-old children;
- increased cognitive costs related to the processing of complex sentences with conflicting cues of case and animacy (*Den Tiger beißt der Schrank*), as compared to complex sentences with cooperating cues of syntax and semantics (*Den Schrank beißt der Tiger*) (Bornkessel-Schlesewsky & Schlesewsky, 2014b; Frisch & Schlesewsky, 2001; Schlesewsky & Bornkessel-Schlesewsky, 2009).

Methods

Participants

Fifty-seven children between the age of 36–48 months participated in the current study. All of them also participated in Experiment 3a and were invited to the present experiment a year (± 2 weeks) later. Twenty 3-year-olds were excluded from the final analysis due to various reasons. Four children had a hearing or neurological disease history. One child was raised in bilingual environment. The EEG recording was not possible in two children. Eight children did not provide representative results on the language developmental test TSVK (for details, see below). One child was below norm level in this test. The data of eight children did not meet the requirement on the minimum number of 15 trials pro condition. Thirty-three participants were included into the final grand average (age range 37–47 months, M_{age} = 41.76 months, *SD* = 3.12 months, 18 girls).

A short version of the TSVK test (Siegmüller et al., 2010) was conducted in order to assess language abilities. The average normed score of the group was 77.45, *SD* = 17.23, range 46–99. That is, all the participants had typically developing language skills.

Materials

The experimental stimuli were identical to the stimuli we used in Experiment 3a with 2-year-old children (for details, see *Materials* in Chapter 5.2).

Procedure

The procedure was the same as in Experiment 3a with 2-year-old children (for details, see *Procedure* in Chapter 5.2). In a few cases, 3-year-olds were seated alone in the comfortable chair, while a caregiver was located close to the child behind the chair.

EEG recording

The EEG data was collected using the same parameters as in previous experiments (for details, see *EEG recording*, Chapter 3.2).

Data analysis

The data analysis was conducted using the same processing algorithm as in Experiments 1a and 3a (for details, see *Data analysis* in Chapters 3.2 and 5.2). Individual ERP data sets were not included into the grand average if the number of accepted sentences did not reach 15 for each of four conditions. Eight datasets were excluded for this reason.

Results

First noun phrase

No differences were observed between object- and subject-first sentences at the first determiner (Figure 5.3.1, left panel). ANOVA revealed interactions with distributional factor LP in two TWs: 0–50 ms ($F(2, 64) = 3.37$, $p = .041$) and 50–100 ms ($F(2, 64) = 3.81$, $p = .027$). The step-down analysis of these interactions did not yield significant differences between conditions in any of left, middle or right areas.

At the first noun, OVS sentences elicited a sustained positivity. The onset of the positivity lied before the onset of the noun (Figure 5.3.1, right panel). Taking into account the temporal characteristics of this deflection, the positivity was qualified as a late response to differences triggered by determiner. Results of the statistical analysis indicated that these differences were significant between 0–200 ms (Table 5.3.1.). In TW 100–150 ms, there was an interaction with distributional factor LP. Syntax effect was significant in all areas of lateral plane.

Table 5.3.1. Syntax effects as calculated at Noun 1 in 2-year-old children.

TW	**Main effect of syntax $F(1, 32)$**	**Syntax × LP (df) F**	**Syntax × LP Resolved**		
			LEFT	**MID**	**RIGHT**
0–50	4.62*				
50–100	5.10*				
100–150	14.00**	(2, 64) 3.31*	11.53**	12.69**	11.99**
150–200	10.91**				

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific ROIs: LEFT, left; MID, midline; RIGHT, right. $p \leq .01$**, $.01 < p \leq .05$*.

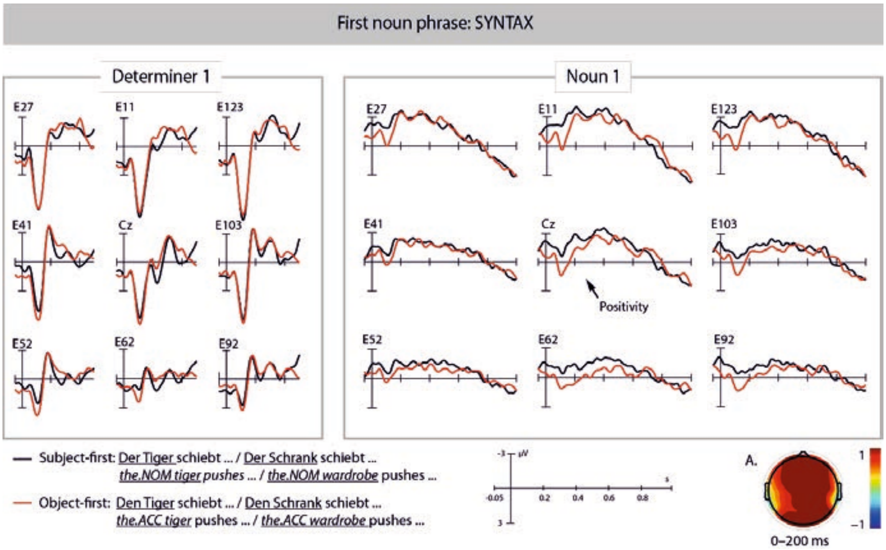

Figure 5.3.1. ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of Determiner 1 (left panel) and Noun 1 (right panel) elicited in 3-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Noun 1, as calculated at object-first minus subject-first difference wave between 0–200 ms.

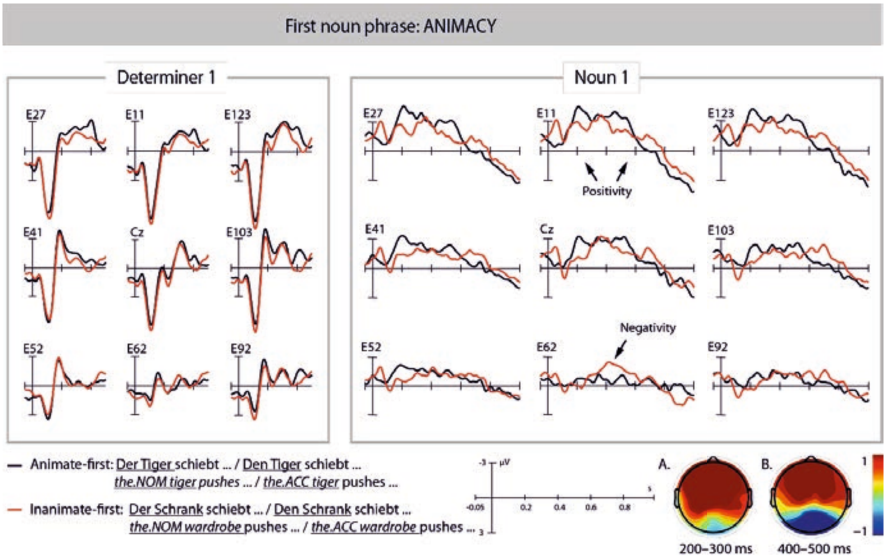

Figure 5.3.2. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 1 (left panel) and Noun 1 (right panel) elicited in 3-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Noun 1, as calculated at inanimate-first minus animate-first difference wave between 200–300 ms. B: Voltage topography of the frontal positivity/the anterior negativity at Noun 1, as calculated at inanimate-first minus animate-first difference wave between 400–500 ms.

As expected, no animacy effects were observed at the first determiner. At the noun, three effects could be discriminated (Figure 5.3.2, right panel). Inanimate-first sentences elicited an early positivity at around 200 ms. Between 400–600 ms, inanimate nouns evoked a positive response in anterior-central areas (e.g., E11) and a negative response in posterior area (e.g., E62). Starting at approximately 600 ms, a sustained negativity at frontal electrode sites could be observed.

These observations were partly confirmed by the analysis of subsequent 50-ms TWs (Table 5.3.2). The first positive response to inanimate noun was significant between 200–300 ms. Analysis of the interactions with distributional factor AP revealed that it was at maximum in anterior areas.

Table 5.3.2. Animacy effects as calculated at Noun 1 in 3-year-old children.

TW	**Main effect of animacy *F*(1, 32)**	**Animacy × AP (df) F**	**Animacy × AP Resolved**		
			ANT	**CENT**	**POST**
		First noun			
200–250	10.01**	(1.38, 44.25) 3.35^{m}	8.65**	10.78**	-
250–300		(1.46, 46.71) 3.91*	5.41*	-	-
400–450		(1.31, 41.84) 9.21**	-	-	5.62*
450–500		(1.24, 39.56) 10.73**	5.75*	-	4.31*
500–550		(1.28, 40.97) 14.68**	7.68**	7.43**	-

Note. TW, time window; AP, anterior-posterior plane. Specific ROIs: ANT, anterior; CENT, central; POST, posterior. $p \leq .01$**, $.01 < p \leq .05$*.

The anterior-central positive deflection was statistically significant in TWs between 450–550 ms, as evidenced by 1) the follow-up analysis of Animacy × AP interactions in corresponding TWs; and 2) by analysis of Animacy × AP × LP interaction in TW 450–500 ms ($F(2.51, 80.30) = 3.99$, $p = .015$) that showed distribution-specific effect of animacy in anterior middle ($F(1, 32) = 5.73$, $p = .023$), anterior right ($F(1, 32) = 6.55$, $p = .015$) and central right ($F(1, 32) = 6.22$, $p = .018$) ROIs.

The posterior negative effect reached significance between 400–500 ms, as indicated by 1) the analysis of Animacy × AP interactions in TWs 400–450 and 450–500 ms; and 2) the analysis of Animacy × AP × LP interaction in TW 400–450 ms ($F(2.70, 86.30) = 4.24$, $p = .010$) and 450–500 ms ($F(2.51, 80.30) = 3.99$, $p = .015$). The effects were distributed in posterior ROIs (400–450 ms: posterior middle *F*(1, 32) = 8.56, *p* = .006, posterior right *F*(1, 32) = 4.45, *p* = .043; 450–500 ms: posterior middle *F*(1, 32) = 6.55, *p* = .015).

The last anterior negative effect was significant in a single TW 650–700 ms (*F*(1, 32) = 4.41, *p* = .044), and due to its short length was considered unreliable.

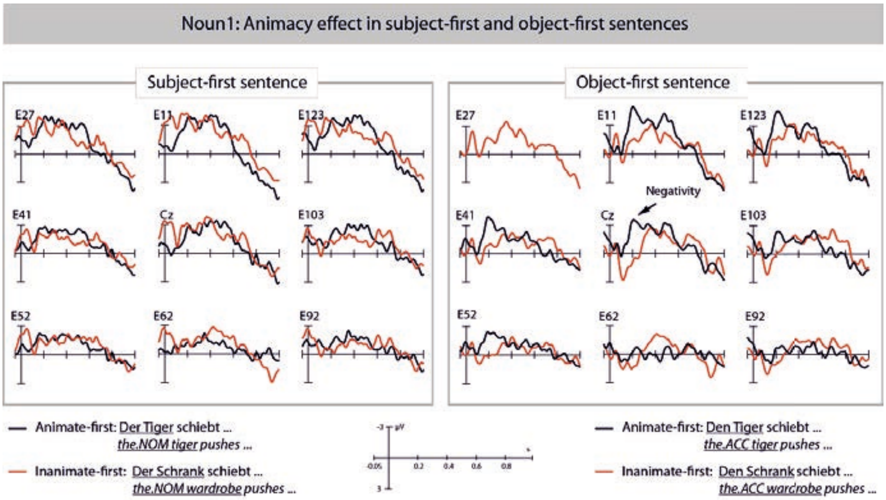

Figure 5.3.3. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Noun 1 in subject-first (left panel) and object-first (right panel) sentences elicited in 3-year-old children. Negativity is plotted upwards.

Finally, interactions involving the factors Animacy and Syntax were observed at the first noun in several TWs. In TWs 100–150 ms and 150–200 ms, there were Syntax × Animacy × AP interactions (Table 5.3.3). In TWs 150–200 ms and 200–250 ms, Syntax × Animacy interactions were found. In TWs 200–250 ms and 250–300 ms, there was a four-way interaction Syntax × Animacy × AP × LP. These interactions were primarily guided by differences between the processing of animate versus inanimate nouns in syntactically complex structures (Figure 5.3.3).

The analysis of animacy effects in SVO sentences revealed no significant differences, whereas ERPs to inanimate and animate nouns differed significantly in OVS conditions. The processing of an inanimate noun evoked a more positive brain response in syntactically complex sentences than an animate noun between 100–300 ms.

Table 5.3.3. Animacy effects as calculated at Noun 1 in 3-year-old children for subject-first and object-first sentences.

TW	Interaction	(df) F	Animacy effects	
			Subject-first	**Object-first**
100–150	S × A × AP	(1.65, 52.67) 6.03**	A × AP (1.62, 51.97) 4.26* → no effects	A × AP: (1.42, 45.50) 3.90* → CENT: 4.76*
150–200	S × A	(1, 32) 6.17*	-	A: 5.52*
	S × A × AP	(1.64, 52.50) 7.83**	-	A: 5.47*
200–250	S × A	(1, 32) 4.91*	-	A: 11.88**
	S × A × AP × LP	(4, 128) 2.44*	-	A: 11.90** A × AP: (1.54,49.40) 5.15* → ANT: 12.43** → CENT: 11.10**
250–300	S × A × AP × LP	(3.13, 100.14) 2.66*	-	A × AP × LP: (2.94, 94.20) 3.29* → AL: 4.67* → CL: 4.56* → CM: 4.19*

Note. TW, time window; S, factor Syntax; A, factor Animacy; AP, anterior-posterior plane; LP, lateral plane. Specific ROIs: ANT, anterior; CENT, central; POST, posterior; AL, anterior left; CL, central left; CM, central middle; p ≤ .01**, .01 < p ≤ .05*.

Verb

Figure 5.3.4 shows syntax (left panel) and animacy (right panel) effects at the verb. Syntactically-complex sentences were associated with a negative deflection that started before the verb onset at fronto-central electrode sites. Inanimate-first sentences elicited a comparable negative response.

The ANOVA's revealed a main effect of syntax in three TWs: 0–50 ms, 50–100 ms and 850–900 ms (*F*(1, 32) = 7.80, *p* = .009, Table 5.3.4). Additionally, an interaction of Syntax × AP × LP (*F*(2.95, 94.49) = 2.79, *p* = .046) was found in TW 50–100 ms. The syntax effect was distributed in anterior left (*F*(1, 32) = 4.93, *p* = .034), anterior middle (*F*(1, 32) = 5.79, *p* = .022), central left (*F*(1, 32) = 7.98, *p* = .008) and central middle (*F*(1, 32) = 10.65, *p* = .003) ROIs.

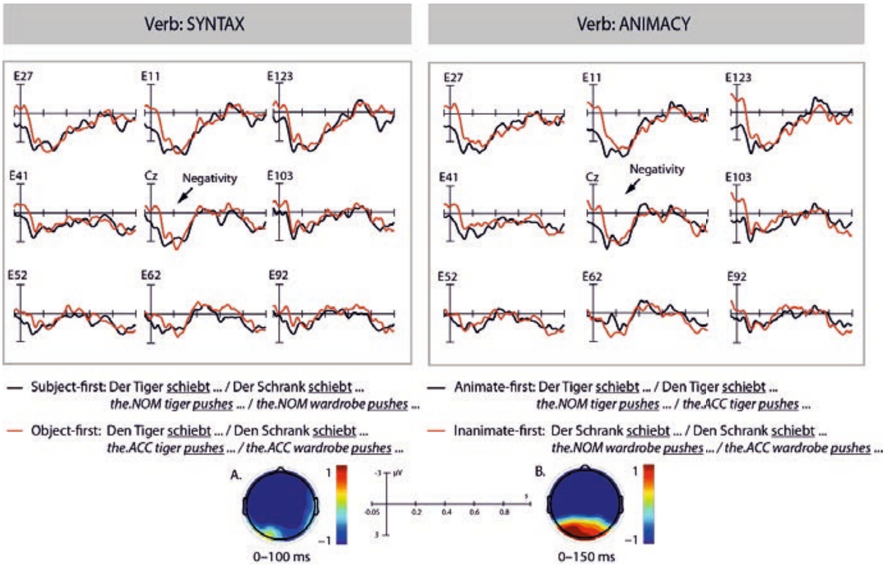

Figure 5.3.4. Left panel: ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of the verb. Right panel: ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of the verb elicited in 3-year-old children. Negativity is plotted upwards. A: Voltage topography of the negativity at the verb, as calculated at object-first minus subject-first difference wave between 0–100 ms. B: Voltage topography of the negativity at the verb, as calculated at inanimate-first minus animate-first difference wave between 0–150 ms.

Statistical analyses showed that semantic features of the preceding noun had a slightly prolonged impact on ERP response at the verb. The main effect of animacy could be confirmed for the time period between 0–100 ms. The step-down analysis of the Animacy × AP interactions indicated that the effect of animacy was mainly distributed in fronto-central areas between 0–150 ms. Furthermore, an interaction Animacy × AP × LP ($F(2.30, 95.97) = 3.04$, $p = .033$) in TW 100–150 ms showed that ERP responses to animate-first and inanimate-first conditions were distinct in anterior left ($F(1, 32) = 6.96$, $p = .013$), anterior middle ($F(1, 32) = 8.55$, $p = .006$), anterior right ($F(1, 32) = 7.26$, $p = .011$) and posterior left ($F(1, 32) = 4.18$, $p = .047$) ROIs.

Finally, interactions involving Syntax, Animacy and distributional factors were found in several TWs. These included a Syntax × Animacy × LP interaction between 600–650 ms ($F(2, 64) = 7.23$, $p = .001$) and a series of Syntax × Animacy × LP × AP interactions between 650–700 ms ($F(2.71, 86.74) = 2.49$, $p = .071$), 850–900 ms $F(2.81, 90) = 4.05$, $p = .011$) and 900–950 ms ($F(2.80, 89.62) =$

2.90, *p* = .043). Although the analysis of these interactions revealed a number of interactions involving animacy in SVO and OVS sentences, the effect of animacy did not reach significance in any of ROIs (Table 5.3.5).

Table 5.3.4. Animacy effects as calculated at the verb in 3-year-old children.

TW	**Main effect of animacy *F*(1, 32)**	**Animacy × AP (df) F**	**Animacy × AP Resolved**		
			ANT	**CENT**	**POST**
0–50	18.13***	(1.20, 38.34) 10.01**	17.79**	17.87**	-
50–100	17.04**	(1.28, 40.88) 13.05**	19.04**	17.88**	-
100–150		(1.26, 40.23) 11.92**	8.75**	-	-

Note. TW, time window; AP, anterior-posterior plane. Specific areas: ANT, anterior; CENT, central; POST, posterior. p ≤ .01**, .01 < p ≤ .05*

Table 5.3.5. Animacy effects as calculated at the verb in 3-year-old children for subject-first and object-first sentences.

TW	**Interaction**	**(df) F**	**Animacy effects**	
			Subject-first	**Object-first**
600–650	S × A × LP	(2, 64) 7.23*	-	A × LP: (2, 64) 3.31* → no effects
650–700	S × A × AP × LP	(2.71, 86.74) 2.50^{m}	-	A × LP: (1.61, 51.66) 3.74* → no effects
850–900	S × A × AP × LP	(2.81, 90) 4.05*	A × AP × LP: (4, 128) 4.02** → no effects	-
900–950	S × A × AP × LP	(2.80, 89.62) 2.90*	A × LP (1.57, 50.27) 3.44* → no effects	-

Note. p ≤ .01**, .01 < p ≤ .05*, .05 < p < 1^{m}.

Second noun phrase

The second determiner in OVS sentences (*der*) elicited a positive ERP response between 200–300 ms, relative to the second determiner in SVO sentences (Figure 5.3.5, left panel). This was confirmed by an analysis of variance in two consequent TWs: 200–250 ms and 250–300 ms.

In TW 200–250 ms, there was a marginally significant main effect of syntax (*p* = .074) and an interaction with distributional factor AP (Table 5.3.6). Analysis of the interaction showed that the ERP effect was distributed in anterior and central areas. Similar distributional pattern was observed in TW 250–300 ms, in which a marginally significant interaction with factor AP was found (*p* = .081).

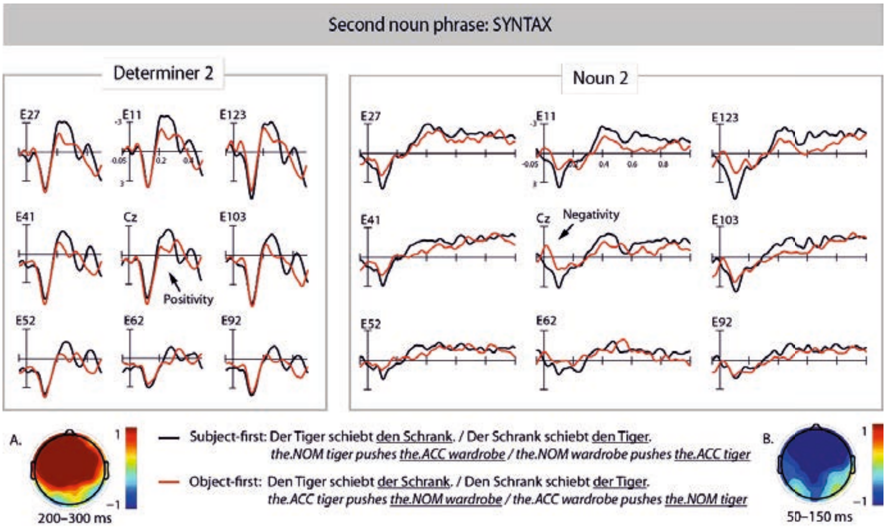

Figure 5.3.5. ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of Determiner 2 (left panel) and Noun 2 (right panel) elicited in 3-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Determiner 2, as calculated at object-first minus subject-first difference wave between 200–300 ms. B: Voltage topography of the negativity at Noun 2, as calculated at object-first minus subject-first difference wave between 50–150 ms.

At the second noun, a biphasic pattern was elicited (Figure 5.3.5, right panel). It consisted of an early negativity (approximately 0–200 ms) and a late positivity (approximately 400–800 ms). ANOVA revealed the main effect of syntax only in TW 100–150 ms. In the preceding TW 50–100 ms, there was an interaction between Syntax and distributional factors AP and LP ($F(2.45, 78.23) = 3.18$, $p = .038$). Step-down analysis showed that the difference between OVS and SVO conditions was significant in anterior right ROI ($F(1, 32) = 9.41$, $p = .004$), as represented by electrode 123 in Figure 5.3.5. In the following TW 150–200 ms, the interaction Syntax × AP × LP was also significant ($F(2.40, 76.63) = 4.08$, $p = .015$), but did not indicate any ROI-specific distributions. Thus, the negative syntax effect at Noun 2 was confirmed for the time period between 50–150 ms.

A positivity that can be seen around 400–800 ms was statistically significant only in one TW 600–650 ms that showed an interaction of Syntax × AP ($F(1.42, 45.41) = 4.39$, $p = .029$). The effect of syntactic complexity was found in anterior area ($F(1, 32) = 5.22$, $p = .029$).

Table 5.3.6. Syntax effects as calculated at NP2 in 3-year-old children.

TW	Main effect of syntax $F(1, 32)$	Syntax × AP (df) F	Syntax × AP Resolved ANT	CENT	POST
		Second determiner			
200–250	3.41^{m}	(1.23, 39.26) 4.40*	5.57*	4.83*	-
250–300	8.32**	(1.35, 43.05) 2.97^{m}	6.27*	10.37**	-
		Second noun			
100–150	4.39*				
600-650		(1.42, 45.41) 4.39*	5.24*	-	-

Note. TW, time window; Specific areas: ANT, anterior; CENT, central; POST, posterior. p ≤ .01**, .01 < p ≤ .05*, .05 < p < 1^{m}.

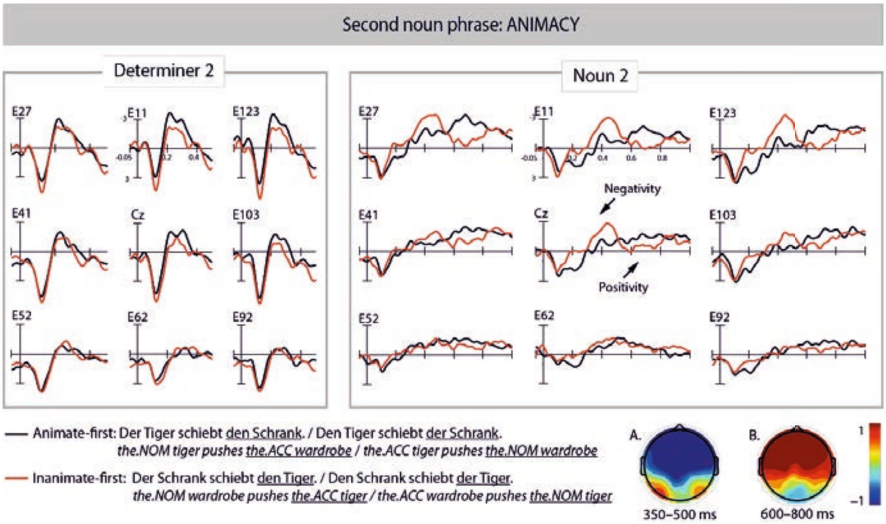

Figure 5.3.6. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 2 (left panel) and Noun 2 (right panel) elicited in 3-year-old children. Negativity is plotted upwards. A: Voltage topography of the negativity at Noun 2, as calculated at inanimate-first minus animate-first difference wave between 350–500 ms. B: Voltage topography of the positivity at Noun 2, as calculated at inanimate-first minus animate-first difference wave between 600–800 ms.

No animacy effects in at least two neighboring TWs were found at the second determiner (Figure 5.3.6, left panel). In contrast, a biphasic ERP pattern was elicited at the second noun by the inanimate-first sentences. Specifically, the animate argument was associated with a positivity that peaked at around 450 ms, and a negativity that was mostly pronounced between 600–800 ms (Figure 5.3.6, right panel).

The negative deflection was statistically confirmed in TWs between 350–500 ms (Table 5.3.7). The analysis of interactions with factor AP showed that the effect was distributed in fronto-central scalp areas. The positive ERP response to the animate noun was significant in TWs between 600–750 ms. The effect was distributed in fronto-central areas, as indicated by the step-down analysis of the Animacy × AP interactions in TWs between 650–800 ms.

Table 5.3.7. Animacy effects as calculated at Noun 2 in 3-year-old children.

TW	**Main effect of animacy *F*(1, 32)**	**Animacy × AP (df) F**	**Animacy × AP Resolved**			**Animacy × LP (df) F**	**Animacy × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
350–400		(1.18, 37.69) 5.06*	5.46*	-	-				
400–450	6.80*	(1.19, 38.16) 4.35*	7.47*	6.61*	-				
450–500	6.89*	(1.49, 47.70) 11.74**	12.95**	6.47*	-				
500–550		(1.35, 43.24) 5.14*	-	-	-	(2, 64) 3.46*	-	-	-
600–650	4.56*								
650–700	7.85**	(1.24, 39.55) 7.71**	11.00**	8.04**	-				
700–750	7.83**	(1.29, 41.22) 5.58*	11.63**	8.05**	-				
750–800		(1.27, 40.52) 4.62*	6.51*	-	-				

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, middle; RIGHT, right. $p \leq .01$**, $.01 < p \leq .05$*.

Finally, there were several interactions involving the factors Animacy and Syntax at the second determiner. The interactions with distributional factors LP and AP were found between 0–100 ms and 200–350 ms (Table 5.3.8). As can be seen in Figure 5.3.7, syntactic manipulation elicited a positive effect both in animate-first and inanimate-first sentences. However, voltage topographies indicate two distinct distributional patterns between 200–300 ms. While the effect of syntax was more pronounced in anterior-right areas for animate-first sentences, the positivity was distributed left-centrally for inanimate-first sentences.

Separate comparisons of ERPs to SVO and OVS sentences were conducted for each semantic condition. The syntax effect was significant only in inanimate-first sentences. In TW 200–250 ms, it was focused in the left areas. In TW 250–300 ms, it was broadly distributed.

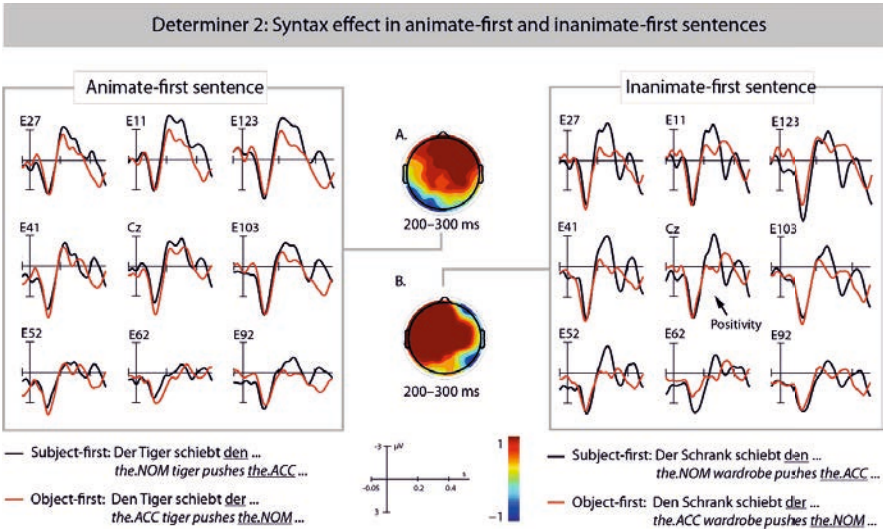

Figure 5.3.7. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 2 in subject-first (left panel) and object-first (right panel) elicited in 3-year-old children. Negativity is plotted upwards. A: Voltage topography of the positivity at Determiner 2, as calculated at object-first minus subject-first difference wave between 200–300 ms in animate-first sentences. B: Voltage topography of the positivity at Determiner 2, as calculated at object-first minus subject-first difference wave between 200–300 ms in inanimate-first sentences.

Table 5.3.8. Syntax effects as calculated at NP2 in 3-year-old children for animate-first and inanimate-first sentences.

TW	Interaction	(df) F	Syntax effects	
			Animate-first	Inanimate-first
Second determiner				
0–50	S × A × AP × LP	(2.86, 91.57) 3.93*	-	-
50–100	S × A × AP × LP	(4, 128) 2.67*	-	-
200–250	S × A × LP	(2, 64) 6.72**	-	S × LP: (1.62,51.70) 4.83* → LEFT: 4.89*
250–300	S × A × LP	(1.67, 53.29) 3.84*	-	S: 6.85*
300–350	S × A × AP	(1.23, 39.29) 4.14*	-	-

Note. S, factor Syntax; A, factor Animacy; TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: LEFT, left. p ≤ .01**, .01 < p ≤ .05*.

To summarize, the processing of object-first sentences was associated with a positive response (200–300 ms) at the second determiner and an early negativity at the second noun (50–150 ms). The syntactic effect at the determiner was modulated by the semantic factor showing different distributional patterns as well as greater differences in inanimate-first than in animate-first conditions. Furthermore, inanimate-first sentences elicited a biphasic pattern at the second noun that consisted of negative (300–500 ms) and positive (650–800 ms) ERP deflections.

Discussion

Experiment 3b aimed at assessing the processing of syntactic and semantic cues by 3-year-old children. Table 5.3.9 represents the main findings of the EEG experiment.

Table 5.3.9. Summary of the main ERP findings in 3-year-old children.

Factor	Determiner 1	Noun 1	Verb	Determiner 2	Noun 2
Syntax	-	Positivity 0–200 ms	Negativity 0–100 ms	Positivity 200–300 ms	Negativity 50–150 ms
Animacy	-	Positivity 200–300 ms Positivity 450–550 ms Negativity 400–500 ms	Negativity 0–150 ms	-	Negativity 350–500 ms Positivity 600–800 ms
Interaction	-	100–300 ms → animacy effects in object-first	-	200–300 ms → syntax effects in inanimate-first	-

Note. Syntactic effects are indicated for object-first sentences relative to subject-first sentences; semantic effects are indicated for inanimate-first sentences relative to animate-first sentences.

Syntactic cues

Detailed analysis of the ERP data revealed two types of syntactic effects. These included syntactic effects at the determiners and syntactic effects at the nouns. Similarly to 2-year-olds, syntactically complex sentences did not elicit a *topicalization* negativity at the first determiner in 3-year-old children. In line with previous studies (Mahlstedt, 2008; Schipke et al., 2012), this result suggests that children at this age were not able to use the first available case marker to predict and store the upcoming structure of the sentence. Yet, as evidenced by a very early positivity at the first noun (0–200 ms) and early negativity at the second noun (50–150 ms) elicited by OVS sentences, 3-year-olds were sensitive to case marking in general. In fact, syntactic effects at the nouns showed a consistent pattern. The processing of the determiner *den* always triggered a positive deflection, as compared to the determiner *der*. Based on this observation, as well as similar patterns obtained by Schipke (2012), the early positive response could hardly be functionally interpreted as a reaction to morphosyntactic violation that has been shown to elicit positivities in children at this age (Silva-Pereyra, Klarman, et al., 2005; Silva-Pereyra, Rivera-Gaxiola, et al., 2005). Rather, this response might have been triggered by physical differences between the determiners *der* and *den* that vary not only in the acoustic features of the vowel and final consonant, but also in natural duration. The positivities evoked by the accusative form reflected children's sensitivity to the differences between articles but did not account for their ability to use the grammatical markers for sentence interpretation.

Similarly as the 2-year-old children, the processing of the OVS structure elicited a positive response directly at the second determiner (200–300 ms). This effect was modulated by animacy of the first argument. In addition to distinct distributional patterns, the positivity elicited by the object-first structure was greater in inanimate-first than in animate-first sentences. The syntactic effect at the second determiner might be explained by the increasing need of reanalysis for object-first sentences. In both subject- and object-first structures, the positional cue points to the agent role of the first argument. However, the second nominative determiner in the OVS structure does not fit this interpretation. In line with data on the processing of complex structures in adults (Bornkessel et al., 2002a, 2003b; Friederici & Mecklinger, 1996; Mecklinger et al., 1995; Rösler et al., 1998), we interpret the early positive effect as reflecting recomputation of syntactic and thematic structure. This process was triggered by the mismatch between the expected prototypical agent-patient structure and nominative case marking at NP2. The fact that the effect was greater in inanimate-first sentences than in animate-first sentences indicates that the conflict between positional cue and animacy is less problematic for 3-year-old children. In other words, a full cooperation between semantic and positional cue is not necessary to launch a retrieval of the second determiner, as was shown in 2-year-olds. This suggestion is in agreement with the results of the behavioral task, in which 3-year-old demonstrated an over-chance performance in subject-first inanimate-first sentences.

Semantic cues

Similar to 2-year-olds, the older group showed effects of animate-inanimate discrimination at both nouns. At the first noun, an early positive response to inanimate nouns was observed. At the second noun, inanimate-first sentences (i.e., animate nouns) elicited a negative deflection, as compared to the animate-first sentences. Both effects were distributed in anterior-central areas. Thus, a consistent neurophysiological pattern of incremental category discrimination could be defined. The processing of inanimate nouns was associated with a positive ERP response.

In contrast to 2-year-old children, animacy did have an effect on the processing of object-first sentences. The semantic ERP effect at the first noun was larger in object-first sentences, as compared to subject-first sentences. This finding may indicate that the processing of conflicting cues at the first NP (*Den Tiger…* 'The.ACC tiger') is more demanding than the processing of non-contradicting cues (*Den Schrank…* 'The.ACC wardrobe'). Previously, the early relational effects of animacy were reported in languages with fixed word order. In English object relative clauses, for example, sentence-initial inanimate nouns elicited a more negative deflection than animate nouns (Weckerly & Kutas, 1999). This effect was attributed to the difficulty of mapping between inanimate nouns and subject function. In German-speaking adults, similar effects were found at the final verb of a complement clause. These were explained by the prototypicality mismatch, that is, by the conflict between the expectation of an ideal Actor and an encountered inanimate argument (Bornkessel-Schlesewsky & Schlesewsky, 2014b; Schlesewsky & Bornkessel-Schlesewsky, 2009). The early effect that was obtained in the current study was not reported previously. We speculate that the effect at NP1 for the 3-year-old can be interpreted as a response to the mismatch between thematic roles assigned by determiner and animacy status of the noun.

Taken together with the results of the behavioral study, in which children performed above chance level in the object-first inanimate-first but not in the object-first animate-first sentences, this finding indicates the decisive role of the first NP in the course of sentence interpretation. This result corroborates with adult data that showed stronger animacy effects for the first as compared to the second noun in a sentence (Kempe & MacWhinney, 1999).

To summarize, the processing of simple subject-first animate-first and inanimate-first sentences did not appear to cause difficulties for 3-year-old children. A mismatch between thematic interpretations that was induced by contradicting accusative case marking and animate noun at the first NP triggered a negative response. This finding indicated that 3-year-olds are aware of the functional meaning of accusative case marking but still attend to animacy as a cue to argument interpretation. However, the acquisition of case marking is not completed in 3-year-olds. The absence of the topicalization negativity at the first determiner and potential syntactic reanalysis at the second determiner indicate that children rely on the positional cue during sentence interpretation.

5.4 Experiment 3c: adults

The purpose of Experiment 3c was to explore the processing of syntactic and semantic cues in adults. It aimed at obtaining a model of mature sentence parsing for developmental comparisons between preschool children and adults. Based on the previous research on the processing of syntactic complexity, adults were hypothesized to use the primarily syntactic cue of case marking for thematic role assignment. These processes were expected to be signaled by

- a ‘topicalization’ negativity occurring at the first determiner in OVS sentences reflecting the establishment of syntactic dependency (Matzke et al., 2002) or subject-first preference (Schipke et al., 2012);
- no further effects of syntax at the second determiner (Schipke et al., 2012). Alternatively, a positivity at the second case marker could appear reflecting the local integration and resolution of dependency (Fiebach et al., 2001, 2002; Wolff et al., 2008).

Animacy was expected to play a minor role in the processing of the relatively simple sentences that were presented in the experiment. Based on the previous studies on the impact of animacy on thematic role assignment within eADM model, we suggested that the processing of object-first structures would elicit a posterior negativity (N400) at the second noun phrase (Frisch & Schlesewsky, 2001; Röhm et al., 2001; Schlesewsky & Bornkessel-Schlesewsky, 2009). This negativity was expected to reflect a prototypicality mismatch between the thematic roles assigned by case and by animacy to NP2 in OVS sentences.

Methods

Participants

Thirty-four adults took part in the current study (age range 21–35 years, M_{age} = 27.32 years, *SD* = 3.7 years, 15 female). All of them were German native speakers recruited from the database of Max Planck Institute for Cognitive and Brains Sciences, Leipzig. None of them reported any neurological diseases. Three participants were excluded from the evaluation. The recordings of two participants did not contain enough data in one or more conditions. One subject was excluded due to technical reasons. The final dataset consisted of 31 EEG recordings (age range 21–35 years, M_{age} = 27.13 years, *SD* = 3.6 years, 14 female). Mean laterality quotient of the final set of the participants was 89% (range 50–100%, *SD* = 15.5%), as assessed by the German version of the Edinburgh Handedness Inventory (Oldfield, 1971). The mean intelligence score in the sample was 120.52 (range 108–134, *SD* = 7.70). The adult participants took part in MMN and Syntax experiments during one session. They were paid 21 Euro for their participation.

Materials

The materials of Experiment 3c were identical to the experiments with children 3a and 3b (for details, see *Materials* in Chapter 5.2).

Procedure

The experimental procedure was the same as in the experiments on auditory discrimination (for details, see *Procedure* in Chapter 3.5). In contrast to children, the instructions were given in written form.

EEG recording

The EEG recordings were conducted in the same manner as for the experiments on auditory discrimination. The impedances were measured before the experiment and kept below 50 kΩ.

Data analysis

Data analysis was conducted in the same manner as with the children data (for details, see *Data analysis* in Chapters 3.2 and 5.2). Thresholds for the automatic rejection of artefact-contaminated ERP data were set to 100 µV (absolute value rejection), and to 5 *SDs* (probability-based rejection). Individual datasets were included in the grand average if they contained at least 20 artefact-free trials pro condition.

Results

First noun phrase

Figure 5.4.1 shows the ERP responses to two syntactic conditions at the first noun phrase. The differences between SVO and OVS sentences could be observed at the determiner between 200–400 ms, as well as at the noun in form of the sustained positive deflection for the OVS structure.

Statistical analysis showed the main effect of syntax at the first determiner between 250–400 ms (Table 5.4.1). The effects had a distributional focus in anterior-central scalp regions, as evidenced by the detailed analysis of interactions in the anterior-posterior plane in these TWs. In time period 300–400 ms, an interaction with factor LP was found. However, the step-down analysis revealed no specific distributional patterns in left-right plane. In three TWs, three-way interactions Syntax × AP × LP were observed. In TW 300–350 ms ($F(4, 120) = 4.39$, $p = .002$), the differences between OVS and SVO structures were found in all nine ROIs ($Fs = 21.98–5.41$, $p = .000056–.027$). In TW 350–400 ms ($F(4, 120) = 6.59$, $p < .001$), the effects could be observed in anterior middle ($F(1, 30) = 8.50$, $p = .007$) and anterior right ($F(1, 30) = 4.55$, $p = .041$), all central (central left: $F(1, 30) = 12.05$, $p = .002$; central middle: $F(1, 30) = 23.19$, $p = 0.000039$;

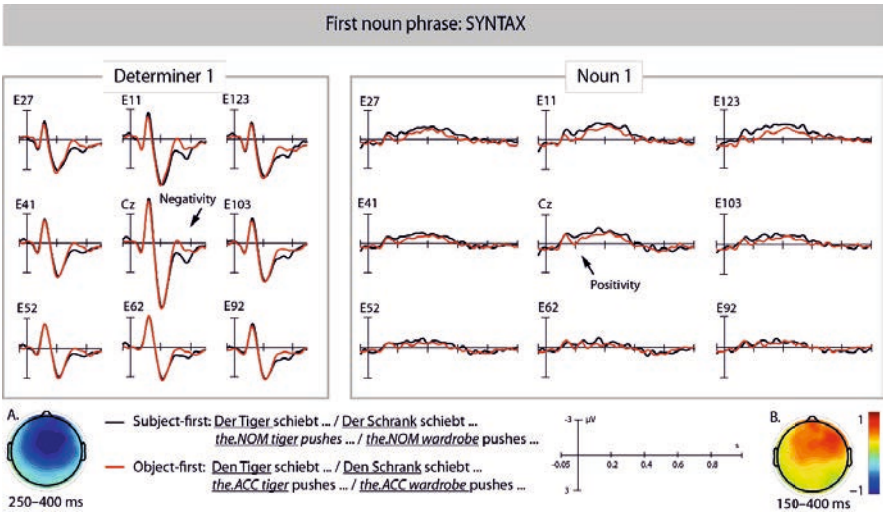

Figure 5.4.1. ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of Determiner 1 (left panel) and Noun 1 (right panel) elicited in adults. Negativity is plotted upwards. A: Voltage topography of the negativity at Determiner 1, as calculated at object-first minus subject-first difference wave between 250–400 ms. B: Voltage topography of the positivity at Noun 1, as calculated at object-first minus subject-first difference wave between 150–400 ms.

Table 5.4.1. Syntax effects as calculated at NP1 in adults.

TW	**Main effect of syntax *F*(1, 30)**	**Syntax × AP (df) F**	**Syntax × AP Resolved**			**Syntax × LP (df) F**	**Syntax × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
				First determiner					
250–300	10.38**	(1.16, 34.91) 4.07*	8.78**	11.66**					
300–350	20.40**	(1.19, 35.82) 4.25*	12.26**	20.95**	8.52**	(2, 60) 5.36**	10.51**	22.22**	20.03**
350–400	13.10**					(2, 60) 5.10**	8.20**	15.84**	9.09**
				First noun					
150–200	9.03**								
200–250	6.95*	(1.14, 34.30) 5.63*	8.66**	7.51**					
250–300	7.17*								
300–350	6.45*								
350–400	7.49**								

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane; ANT, anterior; CENT, central; POST, posterior; LEFT, left; MID, middle; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*.

central right: *F*(1, 30) = 12.35, *p* = .001) and posterior left (*F*(1, 30) = 4.63, *p* = .040) regions. In TW 400–450 ms (*F*(3.11, 93.31) = 2.77, *p* = .044), no ROIs with significant differences between syntactic conditions were found.

Differences between brain responses to OVS and SVO sentences were observed at the first noun. Compared to SVO sentences, the ERPs to OVS sentences showed a positivity between 150–400 ms (Table 5.4.1). In TW 200–250 ms, there were two interactions with distributional factors. The analysis of the interaction Syntax × LP did not further specify distributional pattern of syntax effect. The analysis of the interaction Syntax × AP × LP (*F*(2.54, 76.31) = 2.99, *p* = .044) indicated that the effect of syntactic complexity was distributed in all three anterior (*Fs* = 12.24–4.79, *p* = .001–.037) as well as all three central (*Fs* = 7.29–5.41, *p* = .011–.027) regions of interest.

Visual inspection of the ERP data revealed no effects of animacy at the first determiner (Figure 5.4.2). At the first noun, inanimate-first sentences elicited a biphasic pattern consisting of an early positivity (approx. 200–400 ms) and a late negativity (approx. 600–800 ms) primarily at frontal electrode sites.

Statistical analyses confirmed the differences between brain response to animate-first and inanimate-first sentences at the first noun between 200–400 ms and 550–850 ms (Table 5.4.2). The analysis of interactions in individual TWs showed that the positivity between 200–400 had a right fronto-central scalp distribution. Similarly, the negativity between 550–850 ms was distributed in anterior-central parts. In two TWs, Animacy × AP × LP interactions were found. In TW 750–800 ms (*F*(1.98, 59.28) = 4.75, *p* = .012), the effects were distributed in three anterior ROIs (*Fs* = 12.38–4.81, *p* = .001–.036). In the following TW 800–850 ms (*F*(1.15, 64.35) = 4.02, *p* = .020), the ERP responses to inanimate-first and animate-first sentences differed in all three anterior (*Fs* = 12.92–6.75, *p* = .008–.014) and two central (CM: *F*(1, 30) = 4.22, *p* = .049, CR: *F*(1, 30) = 5.17, *p* = .030) ROIs.

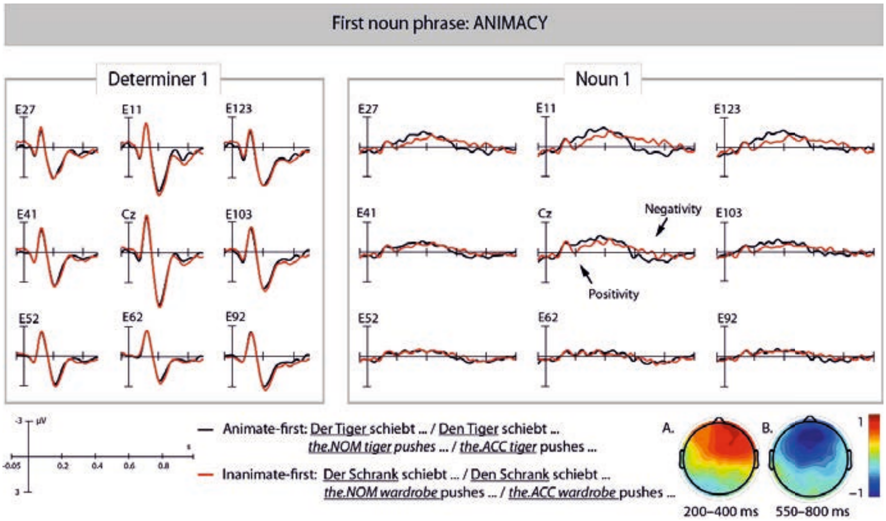

Figure 5.4.2. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 1 (left panel) and Noun 1 (right panel) elicited in adults. Negativity is plotted upwards. A: Voltage topography of the positivity at Noun 1, as calculated at inanimate-first minus animate-first difference wave between 200–400 ms. B: Voltage topography of the negativity at Noun 1, as calculated at inanimate-first minus animate-first difference wave between 550–800 ms.

Table 5.4.2. Animacy effects as calculated at Noun 1 in adults.

TW	**Main effect of animacy *F*(1, 30)**	**Animacy × AP (df) F**	**Animacy × AP Resolved**			**Animacy × LP (df) F**	**Animacy × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
150–200		(1.30, 39.03) 4.84*	-	-	-				
200–250	7.72**	(1.17, 34.98) 7.18**	9.23**	7.74**	-	(1.49, 44.62) 3.78*	-	7.11*	10.55**
250–300		(1.25, 37.35) 8.74**	6.73*	4.39*	-				
300–350		(1.39, 41.80) 6.71**	6.29*	-	-	(2, 60) 3.56*	-	-	6.01*
350–400	6.09*	(1.38, 41.44) 7.66**	10.03**	4.83*					
550–600	4.21*								
600–650	6.85*	(1.45, 43.50) 4.81*	10.84**	4.63*					
650–700	5.03*								
700–750	5.07*	(1.49, 44.61) 5.57*	9.01**	-	-	(2, 60) 4.67*	-	5.43*	6.22*
750–800		(1.49, 44.63) 7.72**	7.71**	-	-				
800–850	5.30*	(1.34, 40.30) 8.36**	9.83**	4.86*	-				

Note. TW, time window; AP, anterior-posterior plane; ANT, anterior; CENT, central; POST, posterior; LP, lateral plane; LEFT, left; MID, middle; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*.

Verb

As can be seen in Figure 5.4.3, the ERP responses to the verb in the two syntactic conditions show slight discrepancies at posterior (e.g., E62) and anterior (e.g., E11) electrodes. On the one hand, the verb in the OVS sentences elicited a negative response at around 650 ms in anterior scalp area. At a very similar time point, a negativity can be seen at the posterior electrodes.

These effects were confirmed by statistical analysis (Table 5.4.3). Repeated measures ANOVA revealed no main effects of animacy at the verb, but a number of interactions with distributional factor in the anterior-posterior plane. The analysis showed that differences reflected by posterior positivity were significant between 600–700 ms. In anterior areas, syntactically complex sentences elicited a negative response between 650–750 ms.

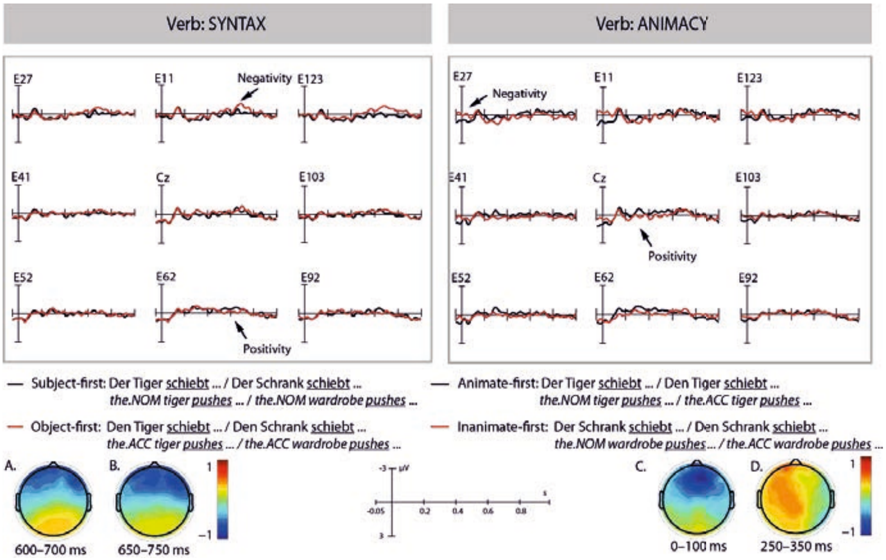

Figure 5.4.3. Left panel: ERP response to subject-first (in black) and object-first (in red) sentences relative to the onset of the verb. Right panel: ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of the verb elicited in adults.Negativity is plotted upwards. A: Voltage topography of the positivity at the verb, as calculated at object-first minus subject-first difference wave between 600–700 ms. B: Voltage topography of the negativity at the verb, as calculated at object-first minus subject-first difference wave between 650–750 ms. C: Voltage topography of the negativity at the verb, as calculated at inanimate-first minus animate-first difference wave between 0–100 ms. D: Voltage topography of the positivity at the verb, as calculated at inanimate-first minus animate-first difference wave between 250–350 ms.

Table 5.4.3. Syntax effects as calculated at the verb in adults.

TW	Main effect of syntax *F*(1, 30)	Syntax × AP (df) F	Syntax × AP Resolved		
			ANT	CENT	POST
550–600		(1.30, 38.84) 4.74*	-	-	-
600–650		(1.16, 34.72) 5.40*	-	-	7.62**
650–700		(1.15, 34.40) 10.81**	8.25**	-	5.31**
700–750		(1.27, 38.21) 5.36*	5.73*	-	-

Note. TW, time window; AP, anterior-posterior plane. Specific areas: ANT, anterior; CENT, central; POST, posterior. p ≤ .01**, .01 < p ≤ .05*.

The comparison of the ERP responses to the verb in animate-first and inanimate-first conditions showed a very early effect of animacy (0–150 ms) at primarily anterior electrode sites (Figure 5.4.3). The significance of this effect was confirmed by repeated measures ANOVA in three consequent TWs: 0–50 ms, 50–100 ms, 100–150 ms (Table 5.4.4).

The inanimate-first sentence also elicited a small positivity around 350 ms. In TW 250–300 ms, the effect was left-lateralized. In the consequent TW 300–350 ms, the main effect of animacy and an interaction with distributional factor LP were found. The analysis of the interaction indicated left and middle distribution of this effect.

Table 5.4.4. Animacy effects as calculated at the verb in adults.

TW	Main effect of animacy F (1, 30)	Animacy × AP (df) F	Animacy × AP Resolved			Animacy × LP (df) F	Animacy × LP Resolved	
			ANT	CENT	POST		LEFT	MID
0–50		(2, 60) 9.64**	10.06**	-	-			
50–100		(1.59, 47.58) 5.63**	5.06*	-	-			
100–150		(2, 60) 10.91**	-	-	7.20*			
250–300						(1.62, 48.51) 3.78*	4.36*	-
300–350	7.45**					(1.43, 42.86) 4.75*	9.67**	8.50**

Note. AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior; CENT, central; POST, posterior; LEFT, left area; MID, middle area; RIGHT, right area. p ≤ .01**, .01 < p ≤ .05*.

To summarize, OVS sentences elicited an almost simultaneous posterior positivity (600–700 ms) and an anterior negativity (650–750 ms) at the verb. In comparison to the animate-first sentences, the verb following an inanimate noun elicited an early negativity between 0–100 ms and a left-lateralized positivity between 250–350 ms.

Second noun phrase

OVS sentences elicited a relatively small positivity at the second determiner (Figure 5.4.4). At the following noun, the processing of complex sentences was associated with an early negativity around 200 ms.

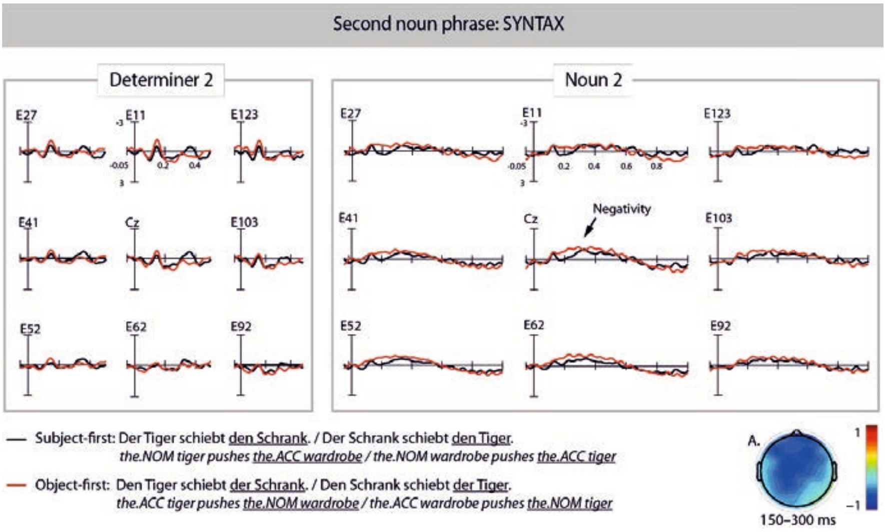

Figure 5.4.4. ERP response to object-first (in black) and subject-first (in red) sentences relative to the onset of Determiner 2 (left panel) and Noun 2 (right panel) elicited in adults. Negativity is plotted upwards. A: Voltage topography of the negativity at Noun 1, as calculated at object-first minus subject-first difference wave between 150–300 ms.

In fact, the differences between syntactic conditions at the second determiner were not significant. At the second noun, the negative ERP effect was confirmed statistically by the results of ANOVA in three consequent TWs between 150–300 ms (Table 5.4.5). In each of them, the main effect of syntax was significant.

Table 5.4.5. Syntax effects as calculated at Noun 2 in adults.

TW	**Main effect of syntax *F*(1, 30)**
150–200	8.71**
200–250	7.65**
250–300	7.06*

Note. TW, time window. p ≤ .01**, .01 < p ≤ .05*.

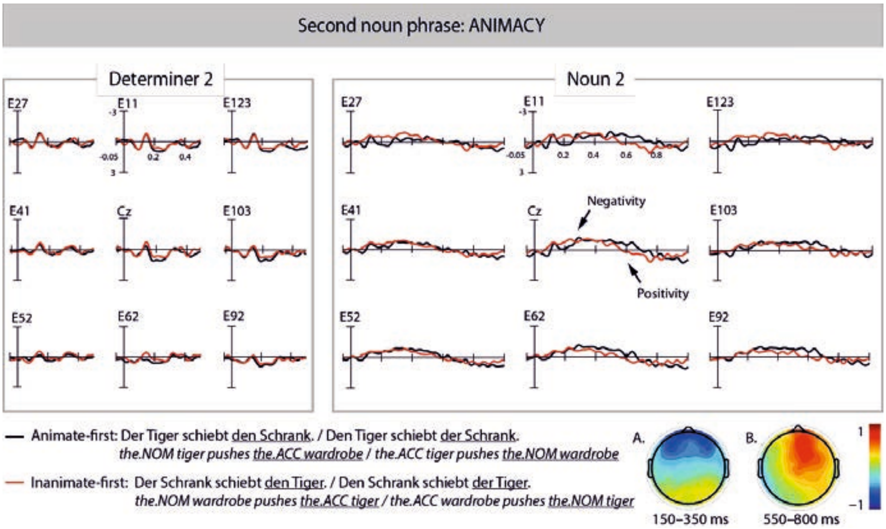

Figure 5.4.5. ERP response to animate-first (in black) and inanimate-first (in red) sentences relative to the onset of Determiner 2 (left panel) and Noun 2 (right panel) elicited in adults. Negativity is plotted upwards. A: Voltage topography of the negativity at Noun 2, as calculated at inanimate-first minus animate-first difference wave between 150–350 ms. B: Voltage topography of the positivity at Noun 2, as calculated at inanimate-first minus animate-first difference wave between 550–800 ms.

No effects of animacy were observed at the second determiner (Figure 5.4.5). At Noun 2, there was a biphasic ERP response to the inanimate-first condition. Animate nouns at the second argument position elicited an early negativity followed by a late positivity.

ANOVA showed that the early negativity was mostly pronounced in TW 200–250 ms, where the main effect of animacy was observed (Table 5.4.6). In surrounding TWs, the effect was observed in anterior scalp areas, as evidenced by step-down analysis of animacy effects in anterior-posterior plane.

The positivity elicited by inanimate-first sentences (i.e., animate nouns) was statistically confirmed in time period between 550–800 ms. In three consecutive TWs, three-way interactions with distributional factors were found. In TW 650–700 ms (*F*(3.32, 99.49) = 3.38, *p* = .018), the animacy effects were distributed in middle anterior (*F*(1, 30) = 6.23, *p* = .018), right anterior (*F*(1, 30) = 6.69, *p* = .015) and right central (*F*(1, 30) = 6.87, *p* = .014) ROIs. Similarly, in TW 700–750 ms (*F*(3.10, 93.07) = 3.58, *p* = 0.16), the differences between animacy conditions were significant in left anterior (*F*(1, 30) = 4.31, *p* = .046), middle anterior (*F*(1, 30) = 9.13, *p* = .005), right anterior (*F*(1, 30) = 7.08, *p* = .012) and middle central (*F*(1, 30) = 5.02, *p* = .033) regions. Finally, in TW 750–800 ms (*F*(4, 120) = 3.54, *p* = .009), only two ROIs showed significant differences between conditions: middle anterior (*F*(1, 30) = 7.24, *p* = .012) and right anterior (*F*(1, 30) = 9.87, *p* = .004).

Table 5.4.6. Animacy effects as calculated at Noun 2 in adults.

TW	**Main effect of animacy *F*(1, 30)**	**Animacy × AP (df) F**	**Animacy × AP Resolved**			**Animacy × LP (df) F**	**Animacy × LP Resolved**		
			ANT	**CENT**	**POST**		**LEFT**	**MID**	**RIGHT**
150–200		(1.38, 41.44) 4.52*	6.61*	-	-				
200–250	8.29**	(1.22, 36.66) 9.20**	17.03**	5.41*	-				
300–350		(1.21, 36.38) 9.50**	5.45*	-	-				
550–600	4.97*					(1.61, 48.28) 6.92**	-	5.67*	10.87**
600–650	4.22*					(1.61, 48.43) 8.66**	-	6.09*	7.52**
650–700						(1.51, 45.42) 6.79**	-	4.28*	9.27**
700–750		(1.32, 39.66) 5.89*	7.56**	-	-	(1.53, 45.88) 3.64*	-	5.81*	-
750–800		(1.28, 38.26) 10.10**	6.52*	-	-				

Note. TW, time window; AP, anterior-posterior plane; LP, lateral plane. Specific areas: ANT, anterior area; CENT, central; POST, posterior; LEFT, left, MID, midline; RIGHT, right. p ≤ .01**, .01 < p ≤ .05*.

To summarize, OVS sentences elicited a negative deflection between 150–300 ms at the second noun. Inanimate-first sentences evoked a biphasic pattern at this noun. It consisted of an early anterior negativity (150–350 ms) followed by a positive response (550–850 ms) that was distributed in middle and right scalp areas.

Discussion

Experiment 3c investigated the processing of semantic and syntactic cues in adults. Adult participants had no comprehension task and listened passively to experimental sentences. The main ERP findings are summarized in Table 5.4.7.

Table 5.4.7. Summary of the main ERP findings in adults.

Factor	Determiner 1	Noun 1	Verb	Determiner 2	Noun 2
Syntax	Negativity 250–400 ms	Positivity 150–400 ms	Negativity 650–750 ms Positivity 600–700 ms	-	Negativity 150–300 ms
Animacy	-	Positivity 200–400 ms Negativity 550–800 ms	Negativity 0–100 ms Positivity 250–350 ms	-	Negativity 150–300 ms Positivity 550–800 ms
Interaction	-	-	-	-	-

Note. Syntactic effects are indicated for object-first sentences relative to subject-first sentences; semantic effects are indicated for inanimate-first sentences relative to animate-first sentences.

Syntactic cues

As expected, adult participants showed an early negative effect at the first determiner (250–400 ms). This result was in agreement with numerous experiments on the processing of syntactic complexity in declarative sentences by adults (Fiebach et al., 2001; Matzke et al., 2002; Rösler et al., 1998; Schipke et al., 2012). In line with some of these studies, this effect can be explained by increasing working memory load that is needed to keep the object in memory until it is integrated in the sentence structure (e.g., Rösler et al., 1998). On the other hand, the early negativity was explained by syntactic factors, such as mismatch between the accusative marking and the parsing principle that is based on subject-first preference (e.g., Schipke et al., 2012). The design of the current study does not allow to disentangle between the two factors that might contribute to the negative deflection at the first determiner. It is clear, however, that the structure of the sentence is maintained very early during sentence processing. The absence of significant effects at the second determiner indicates that retrieval and reordering of arguments does not require cognitive efforts towards the end of the sentence.

Similar as in children, a consistent pattern of response to the determiner *den* was observed at Noun 1 and Noun 2. At both positions, accusative case marking elicited an early (150–300 ms) positive response that had a broad distribution. These effects were explained by sensitivity to acoustic features of the two determiners, including the differences in the vowel, final consonant and overall duration. Crucially, this effect was observed in all three age groups which might indicate its non-syntactic nature.

Object-first sentences evoked a small and short posterior positivity at the verb between 600–700 ms. At the verb, the thematic role of the first argument appears to be integrated with the verb structure. The posterior positivity may reflect the processing costs associated with this process. Supporting evidence comes from the studies on the processing of unambiguously marked complex structures in which posterior positivities were found at the verbs (Felser et al., 2003; Fiebach et al., 2001; Kaan et al., 2000). The small amplitude of this response might be explained by two factors. On the one hand, only one argument had to be integrated at this position, while other studies used stimulus sentences with a final categorizing verb. On the other hand, the participants of the current experiment were not asked to accomplish any comprehension test or to follow any specific aspect of the sentence. In previous studies, posterior positivities were shown to depend on task demands and attention (Hahne & Friederici, 2002; Schacht, Sommer, Shmuilovich, Martienz, & Martin-Loeches, 2014). Thus, it is plausible that the amplitude and the length of posterior positivity in the current study can be explained by the absence of active task during the experiment.

Object-first sentences also elicited a late anterior negativity at the verb between 650–750 ms. Anterior negativities were related to increasing working memory load in studies on language processing (King & Kutas, 1995; Münte, Schiltz, & Kutas, 1998). In the present sentences, the accusative-marked argument and the transitive verb should be kept in memory until the whole verb argument structure is assigned at the second NP. The late anterior negativity observed in the present study might reflect the recruitment of working memory resources that are required for sentence processing until the agent is integrated.

Semantic cues

A coherent pattern of brain response to animacy manipulation was observed in the adult data. Inanimate referents elicited a biphasic response consisting of a positivity (around 150–300 ms) followed by a negativity (550–800 ms) at both arguments. All effects were distributed anterior-centrally on the scalp. Previous studies on category discrimination reported both negative (e.g., Meltzer & Braun, 2013; Weckerly & Kutas, 1999) and positive (e.g., Hata et al., 2013) responses to inanimate nouns in various types of paradigms. Mahlstedt (2008) reported very similar effects related to the processing of inanimate nouns, namely: a negativity (500–900 ms) at NP1, and a positivity (300–400 ms) followed by a negativity (500–900 ms) at NP2 in German subordinate clauses. The negative effects were interpreted as reflecting lexical differences between abstract (in Mahlstedt (2008), animate) and concrete (inanimate) nouns. In the current experiment, no direct relationship between concreteness and animacy could be established. Both animate and inanimate nouns were concrete. Thus, the symmetrical negativity-positivity pattern may reflect the category discrimination between animate and inanimate entities *per se*.

Results of the adult experiment indicate a fully autonomous processing of grammar and animacy in declarative clauses. In contrast to the predictions of the eADM model (Schlesewsky & Bornkessel-Schlesewsky, 2009), no interactions between syntax and semantics were found at any of sentence constituents. The absence of an N400 effect at the second noun phrase might be explained by the influence of wider experimental context. It is possible that the weight of the conflict introduced by animacy decayed during the experiment. For example, experiments by Nieuwland and Van Berkum (2006), in which local violations of animacy were presented, showed that such violations can be gradually neutralized by a supportive context. Such a context was also shown to shift comprehender's preference from animacy-obeying predicate to animacy-violating predicate. Although sentences were presented without auditory or visual supportive context in the current study, the impression of the unrealistic context could develop during the experimental session. However, a post hoc comparison of the processing strategies in the first and in the second halves of the experiment did not revealed significant interactions between factors Syntax, Animacy and Time. Thus, the unrealistic metaphoric context of the experiment did not have an effect on the processing of semantic cue.

To conclude, the findings of the current experiment indicate that adults are sensitive to semantic differences between nouns but primarily rely on syntactic cues during the interpretation of declarative main clauses. As soon as the processor encounters the first case marker, the syntactic structure can be predicted and stored. No additional effort is required at the second argument of simple active sentences.

5.5 Conclusion

The event-related potential study on the processing of syntactic and semantic cues demonstrated that all age groups were sensitive to the differences between articles *der* and *den*, and all age groups were sensitive to the animate-inanimate discrimination. However, only adults were able to maintain the structure of the syntactically complex sentence using the first determiner. Neither 2-year-olds nor 3-year-olds showed a similar syntactic effect on the sentence-initial NP. Children appeared to compute the structure of the sentence at the second determiner. This process was related to the degree of cue cooperation and age. While 2-year-olds showed the effect of structure recomputation in sentences with fully cooperating cues of animacy and word order, 3-year-olds attended to the second determiner in sentences with conflicting cues of animacy and word order.

The ERP data shed light on the offline sentence comprehension in children. Systematic above-chance performance in picture-matching task could be mainly related to the processing of the first NP. Whereas the youngest group performed well in sentences where nominative case marking cooperated with animate nouns, 3-year-olds also pointed correctly in conditions where accusative case marking cooperated with inanimate noun in sentence-initial position.

6 General discussion

6.1 Summary of results

The main goal of the current study was to investigate the processing of complex syntax in early childhood from a behavioral and electrophysiological perspective. Behavioral hypotheses of this study were formulated within the Completion model (Bates & MacWhinney, 1987; MacWhinney, 1987). The theoretical basis for the electrophysiological investigation was provided by the Neurocognitive model of auditory sentence comprehension (Friederici, 2002, 2011, 2012a) and the extended argument dependency model (eADM; Bornkessel-Schlesewsky & Schlesewsky, 2009a; Bornkessel & Schlesewsky, 2006).

Case form of the noun phrase is the most reliable cue of sentence interpretation in German. Despite of its high reliability, German-acquiring children use case marking for thematic role assignment only at the age of 5−7 years. The Competition model suggests that this might be (among other reasons) due the high costs associated with the processing of this cue (Bates & MacWhinney, 1987).

The first study of the present dissertation focused on the question of perceivability of the grammatical cue of case marking. The morphological paradigm of determiners that carry case information in German reveals a number of acoustic similarities. If the grammatical cues cannot be differentiated at a sensory level, they may not be considered as a reliable cue to sentence interpretation. In a series of ERP experiments using a classical oddball paradigm we explored whether 2- and 3-year-old children were able to differentiate between critical case-markers when these are presented beyond sentential context.

The experiments showed that children were able to detect the difference between the two case markers *der* and *den* (Table 6.1.1). The ERP response that reflected this ability consisted of an early and a late negativity. Their peak latencies and peak amplitudes were within the ranges reported previously for speech-related discriminative response in this age.

Table 6.1.1. An overview of the main findings of the ERP study on auditory discrimination between *der* and *den*.

	Contrast	MMN	LN
Peak latency	der/den – den/der	2yo > 3yo > adults	2yo < 3yo
	der – der	3yo > adults	2 yo & 3yo
	den – den	adults	2 yo & 3yo
Peak amplitude	der/den – den/der	2yo ≈ 3yo ≈ adults	2yo > 3yo
	der – der	3yo > adults	2 yo & 3yo
	den – den	adults	2 yo & 3yo

Note. MMN, mismatch negativity; LN, late negativity.

Furthermore, different mismatch responses to *der* and *den* were observed in all age groups. The early discriminative negativity was present both in children and adults for the determiner *der*. It displayed a commonly observed developmental trajectory with characteristic latency and amplitude reduction, as compared between 3-year-olds and adults. In contrast, the discriminative pattern for the determiner *den* underwent a considerable morphological change across age groups. Deviant *den* did not elicit a significant early mismatch response in children, whereas adults showed a traditional mismatch negativity.

The asymmetry of the MMN patterns was primarily explained by the influence of a lexical factor. Compared to the form *der*, the form *den* showed a smaller occurrence frequency both in adult and child speech. Frequency of occurrence in linguistic environment was claimed to be reflected in long-term memory representations of words. We argued that these long-term representations contributed to the asymmetrical pattern of mismatch response (see also Alexandrov et al., 2011; Pulvermüller & Shtyrov, 2006).

The ability to use the determiners for an overt sentence interpretation was investigated using a picture-matching task. It aimed to confirm the findings of the previous behavioral studies that showed children's reliance on semantic cues such as animacy during sentence interpretation (Lindner, 2003). In line with the predictions of the Competition model that suggested an extensive use of redundant cues at the earliest stages of syntax acquisition (coalition-as-prototype principle), 2-year-olds performed systematically well only in sentences with three cooperating cues (Table 6.1.2). Their performance was partly guided by the attention to the animacy cue. Detailed analysis of age-related correlations revealed that the youngest participants (24–29 months) did not attend to the semantic cue, whereas the older half of 2-year-olds oriented towards animacy. Note, however, that 2-year-old children performed well only in sentences in which animacy cue cooperated with word order and case marking. Their accuracy decreased as soon as the animacy contrast was not available or the three cues were in conflict.

Table 6.1.2. An overview of the main findings of the behavioral study.

	Condition	**Cues**	**2-year-olds**	**3-year-olds**
Syntactic manipulation	Subject-first	C, WO	52.47%	79.22% (*)
	Object-first	C	52.56%	57.33%
Syntactic-semantic manipulation	Subject-first animate agent	C, WO, A	59.06% (*)	81.46% (*)
	Subject-first inanimate agent	C, WO	56.62%	70.52% (*)
	Object-first animate agent	C, A	52.59%	59.06% (*)
	Object-first inanimate agent	C	43.68%	50.52%

Note. C, case marking; WO, word order; A, animacy contrast.

Behavioral results for older children indicated that they were not constrained by the full cue cooperation in sentence. Three-year-olds were aware of the role of the accusative case marking for the thematic interpretation. They did not exclusively rely on word order, but were able to integrate lexico-semantic and morphosyntactic features of verb arguments during the interpretation of object-first structures. It was, however, unclear at what point in a sentence the semantic and morphosyntactic cues produced these effects. The ERP experiments aimed at exploring the neural correlates of constituent-wise processing of complex sentences.

Although neither 2- nor 3-year-olds showed an adult-like topicalization negativity at the first determiner in the ERP experiments, both age groups were sensitive to the cue of case marking, as indicated by a positive response to accusative-marked as compared to nominative-marked structures at the nouns (Figure 6.1.1, Panel A). Furthermore, object-first sentences elicited a positive response at the second determiner in both age groups. Our strong claim was that this positivity reflected syntactic/thematic recomputation effort when the unexpected nominative case marker was encountered at the sentence-final NP. This effect was similar to the early positive response or P345 obtained in adults in sentences that require disambiguation or thematic reanalysis (Bornkessel et al., 2002a, 2003b; Friederici & Mecklinger, 1996; Mecklinger et al., 1995; Rösler et al., 1998). However, the observed positivity at the second determiner might only indicate that both 2- and 3-year-old children are aware of the functional meaning of case marking. While this awareness was brought to the overt level in picture-matching task in 3-year-olds, it was probably masked by high cognitive demands that were required in the behavioural experiment in 2-year-olds.

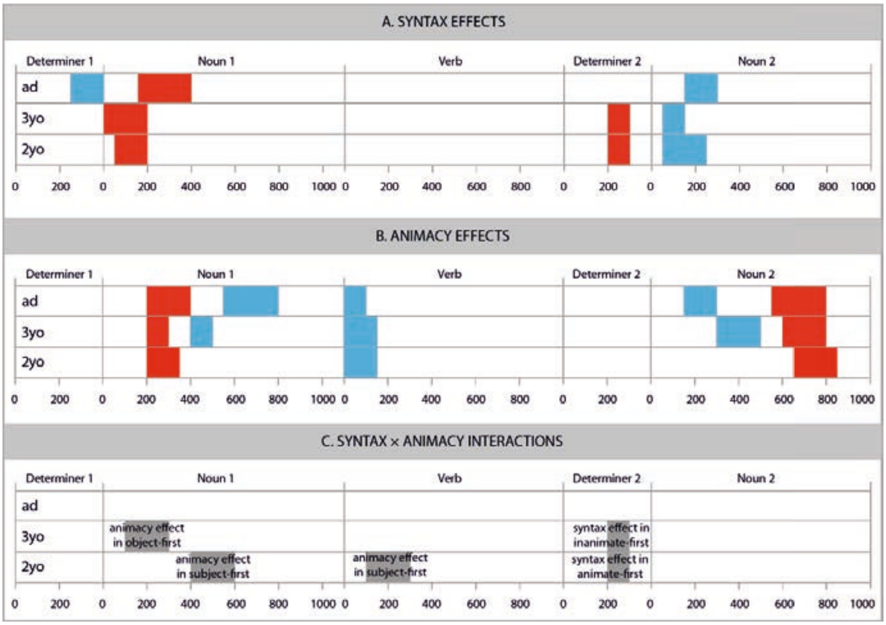

Figure 6.1.1. An overview of the main findings of the ERP study on complex sentence processing in children and adults. Negativities are represented by blue color, positivities are represented by red color. A. Syntax effects are shown for object-first, as compared to subject-first sentences. B. Animacy effects are shown for inanimate-first, as compared to animate-first sentences. C. Results of the analysis of interactions between the factors of animacy and syntax.

The ERP study indicated that children and adults processed the category differences between animate and inanimate entities in a similar manner (Figure 6.1.1, Panel B). All age groups showed a positive effect at the inanimate noun in sentence-initial position. In 3-year-olds and adults, it was followed by a late negative deflection. At the sentence-final position, inanimate-first sentences (i.e., animate nouns) elicited an opposite pattern, namely: an early negativity in 3-year-olds and adults as well as a late positivity in all age groups. Thus, it can be assumed that the processing of lexico-semantic content *per se* may show small differences between adults and children. However, only in children the semantics had impact on the processing of the syntactic structure. This effect was observed at two sentence constituents, namely, at the first noun and the second determiner.

In 2-year-old children, a positivity between 400–600 ms for inanimate versus animate noun was mostly pronounced in subject-first sentences (Figure 6.1.1, Panel C). We speculated that this effect reflected a mismatch between thematic role assignments that were triggered by nominative case marking and animacy. While the case form pointed to the agentive role of the first NP, semantic features of the noun were pointing to its non-agentive role. This effect would not occur if children were not aware of the functional meaning of nominative case-marker.

In agreement with the behavioural study, the processing of animate-inanimate distinction in subject-first sentences did not require additional cognitive efforts in 3-year-olds. The nominative case form in combination with a sentence-initial position of NP were thus a stronger cue than animacy. However, as soon as case marking and word order were in conflict, animate nouns elicited an early negative response in comparison to inanimate nouns. Similarly to 2-year-olds, we interpreted the early negativity as reflecting a mismatch between thematic roles assigned by animacy and case marking. Whereas the accusative case form pointed to the non-agentive role of NP1, its animacy status indicated its agentive role. This result indicates that 3-year-olds are not only sensitive to the cue of case marking but are also aware of the thematic function that it carries.

In both developmental groups, the positivity and its distributional pattern at the second determiner for object-first sentences was related to the animacy of NP1. In 2-year-olds, the effect was more pronounced in animate-first sentences. In older children, the effect was significant in inanimate-first sentences. These results were difficult to interpret. We suggested that the interaction between syntax and animacy at the second determiner reflected the problem of thematic hierarchizing. Specifically, the potential reanalysis process at the second determiner could be triggered in sentences with the cues of word order (sentence-initial position) and semantics (animate) pointing to the agent role of NP1 in 2-year-olds. In other words, the second determiner was retrieved if all other cues were cooperating at the sentence-initial position. This was not the case in 3-year-old children. Here, the processing of the second determiner in animate-first sentences was very similar to the adult response, that is, no effect of case marking was found. Cognitive costs increased during the processing of the second determiner in inanimate-first sentences. In complex sentences of this type only word order was pointing to the agentive role of NP1. On the one hand, this result shows the importance of the positional cue for 3-year-olds' sentence interpretation. On the other hand, it reflected the dissociation of children's processing from the prototype pattern in which the cooperation of all cues was a necessary prerequisite for sentence comprehension.

To sum up, the experiments showed that the first case marker was sufficient to process complex structure for adults. Semantics did not intervene with the syntactic analysis of complex declarative sentences.

Two-year-olds relied on three cooperating cues during behavioural sentence interpretation, including nominative case form, position and animacy. The neurophysiological reality of 2-year-olds' attention to these cues was established in the ERP study, in which an effect reflecting the mismatch between thematic roles assigned by animacy and nominative case marker was observed at NP1. Moreover, presumable recomputation costs at the second determiner were more pronounced in sentences with cooperating word order and animacy cues.

Three-year-olds were able to correctly respond to complex sentences in which case marking and at least one of two other cues (animacy or word order) were pointing to one interpretation. In other words, they were aware of the functional meaning of case marking and started to use it in supportive contexts. In the ERP study, this awareness was reflected by the increased processing costs in sentences with conflicting animacy and accusative case marking at NP1. Although 3-year-olds were already flexible in using semantic cue, they still kept track of word order and launched recomputation process at the second determiner.

6.2 Implications for the neurophysiological model of argument processing

The results of the current study on sentence processing add a new dimension to the model of argument interpretation developed by Bornkessel-Schlesewsky (Bornkessel & Schlesewsky, 2006). They indicate that children's incremental processing of the preverbal argument appears to differ from that of adults primarily during the COMPUTE PROMINENCE step of Phase 2.

As described earlier in this dissertation, Bornkessel and Schlesewsky (2006) explain prominence as a cover term for "the hierarchical status of an argument as determined by application of […] various information types" (Bornkessel & Schlesewsky, 2006, p. 793). This status can be defined in terms of two roles, namely the role of the Actor (Agent prototype) and the role of the Undergoer (Patient prototype). The information types are similar to those that are discussed by the Competition model and include morphological case, argument position, animacy, definiteness, etc. These information types are assumed to be organized as a series of prominence scales with features being named relative to their association to the actor role: nominative > accusative, argument 1 > argument 2, animate > inanimate, definite > indefinite (Bornkessel-Schlesewsky & Schlesewsky, 2009b). Prominence scales are divided into primary and modulating ones. Primary prominence information, such as case marking in German, serves to fix the actor-undergoer hierarchy (Bornkessel-Schlesewsky & Schlesewsky, 2009a, p. 289). Modulating scales that include animacy and position in German, are argued to determine the goodness of fit between the argument and the thematic role (Bornkessel-Schlesewsky & Schlesewsky, 2009a, p. 290). The architecture of the model suggests that features that are relevant for relational processing are activated during Phase 2a. These are used to compute prominence during Phase 2b.

The current experiment has shown that in adult argument processing, morphological information clearly carries the highest weight in the establishing of thematic roles. The processing differences at the first determiner also indicated that the word order scale was activated. Although animacy information was retrieved, as evidenced by the effects induced by animate-inanimate distinction, it had no impact on the assignment of thematic roles in adults.

Two issues arise when concerning the processing of verb arguments in children. The first issue relates to the question whether 2- and 3-year-olds activate the same prominence scales as adults during Phase 2a. The ERP experiments indicate that this appears to be the case. Children's sensitivity to morphosyntactic, semantic and positional cues could be confirmed by the interactions between syntax and animacy at the first noun, by different brain activity in response to the animate-inanimate distinction, and by the retrieval of morphosyntactic information at the second determiner.

The second issue concerns children's ability to weight the prominence features in order to build up an agent-patient hierarchy. To what extend is this process similar to the computation of prominence in adults? The interactions between syntax and animacy at NP1 have shown that the ranking process takes place in children. As predicted by the eADM model, this process is independent of the verb. Crucially, ranking along the morphological scale seems to be age-related. Whereas this scale is not completely formed in 2-year-olds, the nominative > accusative hierarchy is available in older children. However, the adult-like value of this scale for the assignment of thematic roles is not established in 3-year-olds yet. Rather, the morphosyntactic scale appears to be ranked lower or at the same level as animacy and positional scales. Based on the results of the previous experiments, one may speculate that the significance of morphosyntactic scale increases gradually with age and arrives an adult-like value in 5- to 7-year-old children.

6.3 Implications for language acquisition

Our experiments have demonstrated that the awareness of the functional meaning of grammatical markers emerges between the ages of 2 and 3 in German-speaking children. Three-year-olds do not yet completely rely on this knowledge, but are able to comprehend sentences when the grammatical markers cooperate with animacy. The question arises as to why children do not acquire the cues of high reliability in the course of early linguistic development, as it was predicted by the Competition model. Several hypotheses have been proposed to answer this question (cf. Boeg Thomsen & Poulsen, 2015). These hypotheses range from purely functional to purely neuroanatomical approaches. Function-related hypotheses assume that non-biological discourse-driven factors, such as pragmatic immaturity and low frequency of input are primarily responsible for the slow acquisition of the case-marking cue. Neuroanatomical accounts suggest that biological factors such as maturation of auditory and language networks maybe related to the late development of complex syntax comprehension in children.

First, slow acquisition of German case marking may be explained by the limited understanding of pragmatic reasons of word order variations, or the lack of functional readiness (Bates & MacWhinney, 1989). Some researchers have related the inability to interpret grammatical markers to the lacking capacity to integrate contextual information, that is, to assimilate the pragmatic grounds of syntactic variation (Chan et al., 2009). It should be noted, however, that a very recent study with Danish preschoolers has challenged the view that young children are not able to monitor the context and use it for interpretation of non-canonical structures (Boeg Thomsen & Poulsen, 2015).

Second, the occurrence frequency of sentences in which grammatical cues alone are indicative of thematic relationships has been shown to be very low both in adult-to-adult and child-directed speech (Chan et al., 2009; Dittmar et al., 2008). For example, case marking alone marked thematic roles in less than 1% of sentences analyzed by Dittmar et al. (2008). Usage-based accounts suggested that German children are slow in acquisition of case marking because they do not often encounter sentences in which they may exclusively use case marking for interpretation. Our study shows that the impact of occurrence frequency of the item in linguistic environment should not be underestimated. Even isolated grammatical markers with diverging distributional patterns, such as *der* and *den*, elicited morphologically different brain responses in children. Therefore, one cannot exclude the possibility that the late functional use of case markers for sentence interpretation is related to the input frequency of respective word forms.

Moreover, cue coalitions have been shown to play an important role in sentence interpretation of young children. Two-year-olds were successful only in sentences with maximal marking of agent-patient roles and retrieved the second determiner only in sentences with two cooperating cues at NP1. Three-year-olds performed correctly in sentences with two cooperating cues and retrieved the second determiner in sentences without cooperating animacy. None of the groups showed above-chance performance in sentences with only one cue of case marking available and showed adult-like ERP response to the first determiner. Distributional features of prototype sentences were not explicitly explored in the current project. Other studies show, however, that in child-directed speech cue coalitions occur more frequently than cue conflicts (e.g., Dittmar, 2009). Therefore, our data supports the explanation that the probabilistic characteristics of the input (i.e., a low proportion of sentences in which only grammatical cues indicate thematic roles and a high proportion of sentences in which multiple cues are cooperating) might account for the late emergence of the functional meaning of case marking.

The third explanation suggests that purely perceptual constraints have an effect on the acquisition of case because grammatical words are usually not accented in sentence (Bates & MacWhinney, 1987; Szagun, 2004). In the neurobiological perspective, the question arises whether young children’s auditory system is mature enough to automatically discriminate between words that carry grammatical meaning. The current study gives a positive answer to this question. Despite of the fact that the ability to differentiate between determiners was related to the distributional features of the forms in discourse, both developmental groups were clearly able to distinguish between *der* and *den*.

The fourth (neuroanatomical) account, suggests that the lacking ability to comprehend object-first sentences by very young children might be due to the immaturity of brain structures that were claimed to support the processing of syntactic complexity. Recent analyses of the neuroanatomical prerequisites of language development (e.g., Brauer, Anwander, & Friederici, 2011; Brauer, Anwander, Perani, & Friederici, 2013; Pujol et al., 2006; Skeide, Brauer, & Friederici, 2015) argued that the maturation of white matter bundles was related to language development in general and to the function of sentence processing mechanisms in particular. Specifically, the development of the dorsal pathway connecting BA44 and the posterior superior temporal gyrus/superior temporal sulcus was related to the ability to process complex structures (Friederici, 2012b; Friederici, Oberecker, & Brauer, 2012). Furthermore, the grey matter probability in the left inferior temporal gyrus and the left inferior frontal gyrus was shown to be positively correlated to the ability of 5- to 8-year-old children to interpret complex sentences (Fengler, Meyer, & Friederici, submitted). Although these findings may confirm the association between the developmental state of specific brain structures and children's ability to comprehend complex syntax, the casual relationship between neuroanatomical structure and linguistic function has not been established directly. The current study has shown different neurophysiological patterns of case-marker processing in adults and children that might be explained structurally, that is, by the immaturity of the dorsal pathway and low grey matter volume in syntax-related brain areas. However, our results are hard to interpret within the structure-related account. One may hypothesize a positive relation between the structure maturity and the presence of ERP response at the first determiner a well as absence of the ERP response at the second determiner. Future experiments might address the relationship between 3-year-olds' ability to produce a correct behavioural response to complex sentences with supportive semantic cues, positivity at the second determiner and structural characteristics of white/grey matter.

Finally, the results obtained in the current study are compatible with a synthesizing account that suggests that the amount of experience with syntactically complex structures shapes the brain efficiency to process such structures during early development (Brauer et al., 2011). This process may take place until the age of seven. Continuous involvement of specific brain areas and connections between them allows a more powerful processing of complex linguistic information from school age on. Two- and three-year-olds whose acoustic and syntactic processing was related to the availability of units and structures in the linguistic environment, belong to the initial phases of this developmental trajectory.

7 Concluding remarks

The present thesis investigated the processing of syntactic complexity in young children and adults. It focused on the comprehension of topicalized structures in which two case forms, nominative and accusative, unambiguously marked thematic roles of sentence participants.

Three issues were addressed in the current experiments. First, the question of *identification* of case marking was examined. Our findings challenged the account of high costs related to the acoustic processing of case markers as a barrier to sentence interpretation in early childhood. Second, the *functional* use of case markers for offline sentence interpretation was investigated. We showed that children start to use accusative case marking in supportive contexts at the end of the fourth year of their life. Finally, the study offered the first *neurophysiological* insights in the processing of structural complexity at the initial stages of syntax development. While the processing efforts of 2-year-olds were focused on the nominative case marking, 3-year-old children were aware of the functional meaning of accusative case form in the topicalized object. These conclusions were made on the basis of electrophysiological findings that evidenced semantic-syntactic integration efforts early in the sentence in both developmental groups. Taken together, the findings of the experiments on the offline and online sentence processing indicated that the first steps in the use of case marking for sentence interpretation occur earlier than it was shown by previous behavioural studies.

8 Abbreviations

ACC, accusative
DAT, dative
eADM, extended Argument Dependency Model
EEG, electroencephalography
ELAN, early left anterior negativity
ERP, event-related potential
GEN, genetive
ISI, interstimulus interval
LAN, left anterior negativity
LDN, late descriminative negativity
lMMN, late mismatch negativity
MLU, mean length of utterance
MMN, mismatch negativity
NOM, nominative
NP, noun phrase
pMMR, positive mismatch response
RMS, root mean square
RON, reorientation negativity
sMMN, syntactic mismatch negativity
VOT, voice onset time

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11 Appendix A: Stimuli for Experiment 2

Subject-first, animate agent, animate patient

Der Igel tritt den Hund.
Der Igel zieht den Tiger.
Der Vogel tritt den Tiger.
Der Vogel wirft den Igel.
Der Tiger beißt den Vogel.
Der Tiger zieht den Fuchs.
Der Esel beißt den Fuchs.
Der Esel schiebt den Igel.
Der Fuchs haut den Hund.
Der Fuchs schiebt den Esel.

Object-first, animate agent, animate patient

Den Hund tritt der Igel.
Den Tiger zieht der Igel.
Den Tiger tritt der Vogel.
Den Vogel beißt der Tiger.
Den Fuchs zieht der Tiger.
Den Fuchs beißt der Esel.
Den Vogel schiebt der Esel.
Den Hund haut der Fuchs.
Den Igel beißt der Fuchs.
Den Fuchs tritt der Hund.

Subject-first, animate agent, inanimate patient

Der Igel tritt den Keks.
Der Igel zieht den Kuchen.
Der Igel haut den Schrank.
Der Vogel haut den Keks.
Der Vogel zieht den Turm.
Der Tiger beißt den Schrank.
Der Esel schiebt den Ball.
Der Fuchs haut den Turm.
Der Fuchs beißt den Keks.
Der Hund tritt den Topf.

Object-first animate agent, inanimate patient

Den Topf tritt der Igel.
Den Schrank zieht der Igel.
Den Keks haut der Vogel.
Den Topf wirft der Vogel.
Den Topf beißt der Tiger.
Den Kuchen schiebt der Tiger.
Den Keks wirft der Tiger.
Den Ball schiebt der Esel.
Den Turm haut der Fuchs.
Den Keks schiebt der Fuchs.

Subject-first, inanimate agent, animate patient

Der Keks tritt den Igel.
Der Keks zieht den Vogel.
Der Keks wirft den Esel.
Der Keks haut den Fuchs.
Der Kuchen haut den Igel.
Der Topf beißt den Fuchs.
Der Topf wirft den Vogel.
Der Turm beißt den Esel.
Der Schrank haut den Esel.
Der Ball tritt den Tiger.

Object-first, inanimate agent, animate patient

Den Vogel zieht der Keks.
Den Fuchs wirft der Keks.
Den Igel haut der Kuchen.
Den Esel wirft der Kuchen.
Den Fuchs beißt der Topf.
Den Tiger schiebt der Topf.
Den Igel wirft der Topf.
Den Esel beißt der Turm.
Den Esel haut der Schrank.
Den Igel schiebt der Schrank.

12 Appendix B: Stimuli for Experiment 3

Subject-first, animate-first

Der Igel tritt den Keks.
Der Igel zieht den Kuchen.
Der Igel schlägt den Topf.
Der Igel wirft den Turm.
Der Igel haut den Schrank.
Der Vogel tritt den Ball.
Der Vogel haut den Keks.
Der Vogel schlägt den Kuchen.
Der Vogel fängt den Topf.
Der Vogel zieht den Turm.
Der Tiger beißt den Schrank.
Der Tiger zieht den Ball.
Der Tiger schiebt den Keks.
Der Tiger wirft den Kuchen.
Der Tiger kneift den Topf.
Der Esel beißt den Turm.
Der Esel kneift den Schrank.
Der Esel schiebt den Ball.
Der Esel fängt den Keks.
Der Esel hebt den Kuchen.
Der Fuchs hebt den Topf.
Der Fuchs haut den Turm.
Der Fuchs kratzt den Schrank.
Der Fuchs trägt den Ball.
Der Fuchs beißt den Keks.
Der Hund hebt den Ball.
Der Hund kneift den Kuchen.
Der Hund kratzt den Turm.
Der Hund trägt den Schrank.
Der Hund tritt den Topf.

Object-first, animate-first

Den Igel tritt der Keks.
Den Vogel zieht der Keks.
Den Tiger schlägt der Keks.
Den Fuchs wirft der Keks.
Den Esel trägt der Keks.
Den Hund tritt der Kuchen.
Den Igel haut der Kuchen.
Den Vogel schlägt der Kuchen.
Den Tiger fängt der Kuchen.
Den Esel wirft der Kuchen.
Den Fuchs beißt der Topf.
Den Hund zieht der Topf.
Den Tiger schiebt der Topf.
Den Igel wirft der Topf.
Den Vogel fängt der Topf.
Den Esel beißt der Turm.
Den Fuchs kneift der Turm.
Den Hund schiebt der Turm.
Den Igel fängt der Turm.
Den Vogel kratzt der Turm.
Den Tiger hebt der Schrank.
Den Esel haut der Schrank.
Den Fuchs kratzt der Schrank.
Den Hund trägt der Schrank.
Den Igel schiebt der Schrank.
Den Hund hebt der Ball.
Den Vogel kneift der Ball.
Den Esel kratzt der Ball.
Den Tiger trägt der Ball.
Den Fuchs schlägt der Ball.

Subject-first, inanimate-first

Der Keks tritt den Igel.
Der Keks zieht den Vogel.
Der Keks schlägt den Tiger.
Der Keks wirft den Esel.
Der Keks haut den Fuchs.
Der Kuchen tritt den Hund.
Der Kuchen haut den Igel.

Object-first, inanimate-first

Den Topf tritt der Igel.
Den Schrank zieht der Igel.
Den Keks schlägt der Igel.
Den Turm wirft der Igel.
Den Kuchen trägt der Igel.
Den Ball tritt der Vogel.
Den Keks haut der Vogel.

Subject-first, inanimate-first (continued)

Der Kuchen schlägt den Vogel.
Der Kuchen fängt den Tiger.
Der Kuchen zieht den Esel.
Der Topf beißt den Fuchs.
Der Topf zieht den Hund.
Der Topf schiebt den Igel.
Der Topf wirft den Vogel.
Der Topf kneift den Tiger.
Der Turm beißt den Esel.
Der Turm kneift den Fuchs.
Der Turm schiebt den Hund.
Der Turm fängt den Igel.
Der Turm hebt den Vogel.
Der Schrank hebt den Tiger.
Der Schrank haut den Esel.
Der Schrank kratzt den Fuchs.
Der Schrank trägt den Hund.
Der Schrank beißt den Igel.
Der Ball hebt den Hund.
Der Ball kneift den Vogel.
Der Ball kratzt den Esel.
Der Ball trägt den Fuchs.
Der Ball tritt den Tiger.

Object-first, inanimate-first (continued)

Den Kuchen schlägt der Vogel.
Den Turm fängt der Vogel.
Den Topf wirft der Vogel.
Den Topf beißt der Tiger.
Den Ball zieht der Tiger.
Den Kuchen schiebt der Tiger.
Den Keks wirft der Tiger.
Den Schrank fängt der Tiger.
Den Turm beißt der Esel.
Den Schrank kneift der Esel.
Den Ball schiebt der Esel.
Den Keks fängt der Esel.
Den Kuchen kratzt der Esel.
Den Topf hebt der Fuchs.
Den Turm haut der Fuchs.
Den Schrank kratzt der Fuchs.
Den Ball trägt der Fuchs.
Den Keks schiebt der Fuchs.
Den Ball hebt der Hund.
Den Kuchen kneift der Hund.
Den Turm kratzt der Hund.
Den Schrank trägt der Hund.
Den Topf schlägt der Hund.

13 Appendix C: Acoustic analysis of the experimental stimuli

13.1 Duration

The latencies of constituent onsets and offsets were collected automatically using `shell` scripts. Mean word durations are represented in Figure 13.1.1 for all six conditions. Duration discrepancies between conditions were tested by repeated measures ANOVA with one (Syntax) and two (Syntax, Animacy) factors for corresponding experimental designs.

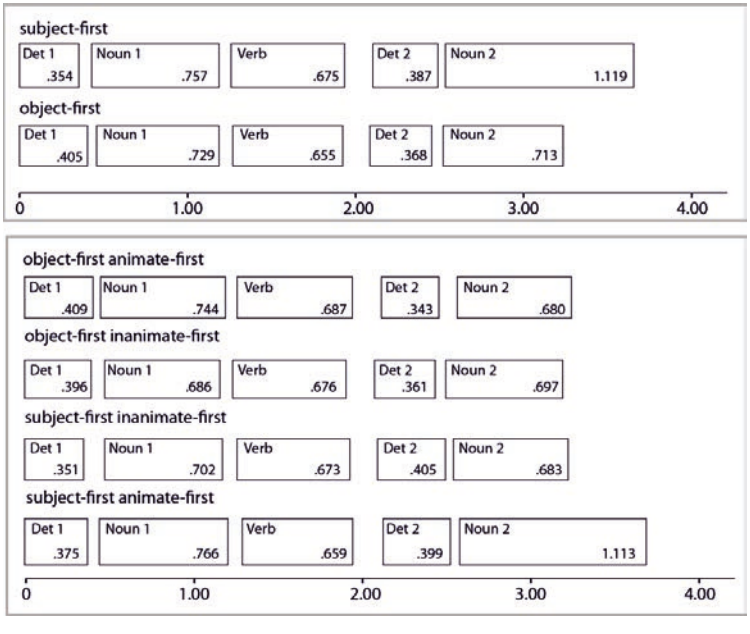

Figure 13.1.1. Duration parameters of individual words in syntactic (upper panel) and syntactic-semantic (bottom panel) contrasts.

Statistical analysis of stimuli in purely syntactic conditions indicated that sentence-initial *den* was longer than sentence-initial *der* ($F(1, 29) = 25.34$, $p < .001$). Both nouns in object-first condition were shorter than nouns in subject-first condition (N1: *F*(1, 29) = 4.38, *p* = .045; N2: *F*(1, 29) = 418.66, *p* < .001, Table 13.1.1).

Table 13.1.1. Analysis of variance as calculated for parameter Duration of the stimuli that were used in syntactic manipulation.

	Determiner 1	**Noun 1**	**Verb**	**Determiner 2**	**Noun 2**
Duration	Object-first > subject-first	Object-first < subject-first	-	-	Object-first < subject-first

In sentences of syntactic-semantic contrast, duration differences were found for grammatical markers (Table 13.1.2). The sentence-initial *den* was longer than sentence-initial *der* (.40 s versus .36 s; *F*(1, 29) = 44.91, *p* < .001). The second determiner in object-first sentences *der* was shorter than the second determiner in subject-first sentences *den* (.35 versus .40 s, *F*(1, 29) = 65.13, *p* < .001). In animate-first sentences, the first determiner was approximately 20 ms longer than in inanimate-first sentences (.39 s versus .37 s; *F*(1, 29) = 5.52, *p* = .029).

Lexical words also differed in duration. On the one hand, the first noun in animate-first condition was in average longer than the first noun in inanimate-first condition (.76 s versus .69 s; *F*(1, 29) = 5.16, *p* = .031). At the second argument position, inanimate noun was longer than the animate noun (.90 s versus .69 s; *F*(1, 29) = 129.98, *p* < .001). Therefore, there was no general relationship between noun animacy and its duration within the sentence.

On the other hand, the main effect of Syntax was observed at both arguments. In object-first sentences, the first noun was slightly shorter than in subject-first sentences (.72 s versus .73 s, *F*(1, 29) = 4.48, *p* = .043). Furthermore, in object-first sentences, the second noun was much shorter than in subject-first sentences (.69 s versus .90 s , *F*(1, 29) = 129.98, *p* < .001). Thus, no relationship between noun duration and preceding determiner within sentence was found.

Table 13.1.2. Analysis of variance as calculated for parameter Duration of the stimuli that were used in syntactic-semantic manipulation.

	Determiner 1	**Noun 1**	**Verb**	**Determiner 2**	**Noun 2**
Duration SYNTAX	Object-first > subject-first	Object-first < subject-first	-	Object-first < subject-first	Object-first < subject-first
Duration ANIMACY	Inanimate-first < animate-first	Inanimate-first < animate-first	-	-	Inanimate-first < animate-first

13.2 Intensity

The following intensity parameters were measured for each sentence constituent: intensity at the word onset, intensity at the word offset, the maximum intensity peak, and the minimum intensity peak. The measurements were conducted using Praat (Boersma & Weenink, 2014) with time step of 20 ms and pitch floor of 120 Hz.

In syntactic contrast, there were intensity differences at the onset of the first determiner with *den* having a greater intensity than *der* (57.92 dB versus 55.49 dB, *F*(1, 29) = 6.75, *p* = .015). No intensity effects were found at the first noun and at the verb. There were intensity discrepancies at the second argument position. First, intensity at the offset of the second determiner was greater in subject-first condition than in object-first condition (52.79 dB versus 47.02 dB; *F*(1, 29) = 6.03, *p* = .020). Second, the intensity at the onset of the following noun differed significantly between syntactic conditions with nouns in subject-first sentence having a greater onset intensity than nouns in object-first sentences (56.17 dB versus 49.49 dB; *F*(1, 29) = 31.38, *p* < .001). The results of this analysis are summarized in Table 13.2.1.

Table 13.2.1. Analysis of variance as calculated for four parameters of Intensity of the stimuli that were used in syntactic manipulation.

	Determiner 1	**Noun 1**	**Verb**	**Determiner 2**	**Noun 2**
Intensity at onset	Object-first > subject-first	-	-	-	Object-first < subject-first
Intensity maximum	-	-	-	-	-
Intensity minimum	-	-	-	-	-
Intensity at offset	-	-	-	Object-first < subject-first	-

In syntactic-semantic contrast, there were differences at the first argument position. Determiners differed in terms of their maxima with *den* having a lower intensity maximum than *der* (78.17 dB versus 77.67 dB, *F*(1, 29) = 11.15, *p* = .002). Intensity at the onset of the first noun in inanimate-first condition was greater than intensity at the onset of the first animate noun (57.64 dB versus 52.90 dB, *F*(1, 29) = 8.12, *p* = .008). However, intensity maximum of the sentence-initial inanimate noun was greater than the intensity maximum of the animate noun in this sentence position (76.15 dB versus 74.98 dB, *F*(1, 29) =

10.06, p = .004). Comparison of intensity minima at this noun also revealed a Syntax × Animacy interaction (F(1, 29) = 10.62, p = .003) that was driven by greater syntax effect for animate-first conditions. Follow-up confirmed significant syntax effect for animate-first conditions (35.48 dB versus 39.46 dB, F(1, 29) = 11.08, p = .002), whereas the effect for inanimate-first conditions was not significant (37.90 dB versus 37.21 dB, F(1, 29) = .35, p = .558).

Intensity characteristics also differed at the second argument position. Intensity at the onset of the second determiner in object-first structures *der* was lower than that of the second determiner in subject-first structures *den* (54.44 dB versus 55.61 dB, F(1, 29) = 5.76, p = .023). Intensity maxima of determiner *der* was higher than that of the determiner *den* (76.46 dB versus 75.93 dB, F(1, 29) = 7.05, p = .013). ANOVA that evaluated the intensity minima showed a Syntax × Animacy interaction (F(1, 29) = 4.98, p = .034) that was guided by greater syntax effect in animate-first conditions than in inanimate-first conditions. In fact, the differences between syntactic conditions in animate-first sentences were statistically significant (51.70 dB versus 57.07 dB, F(1, 29) = 815.41, p < .001), whereas such differences in inanimate-first sentences were not (56.08 dB versus 55.36 dB, F(1, 29) = .10, p = .751).

Analysis of intensity at the onset of the second noun revealed an effect of Animacy (F(1, 29) = 24.25, p < .001). The second (inanimate) noun in animate-first conditions had a greater onset intensity that the second (animate) noun in inanimate-first condition (55.56 dB versus 51.46 dB). There were also significant differences in intensity offset. Namely, intensity at the offset of the second (inanimate) noun in animate-first condition was lower than offset intensity at the second (animate) noun (31.14 dB versus 33.19 dB, F(1, 29) = 6.28, p = .018). Table 13.2.2 summarizes the results of intensity analysis of stimulus sentences in syntactic-semantic contrast.

Table 13.2.2. Analysis of variance as calculated for four parameters of Intensity of the stimuli that were used in syntactic-semantic manipulation.

		Determiner 1	**Noun 1**	**Verb**	**Determiner 2**	**Noun 2**
SYNTAX	Intensity at onset	-	-	-	Object-first < subject-first	-
	Intensity maximum	Object-first < subject-first	-	-	Object-first > subject-first -	-
	Intensity minimum	-	Object-first > subject-first in animate-first conditions	-	Object-first > subject-first in animate-first conditions	-
	Intensity at offset	-	-	-	-	-
ANIMACY	Intensity at onset	-	Inanimate-first > animate-first	-	-	Inanimate-first < animate-first
	Intensity maximum	-	Inanimate-first > animate-first	-	-	-
	Intensity minimum	-	-	-	-	-
	Intensity at offset	-	-	-	-	-

13.3 Fundamental frequency

The following pitch measures were collected using Praat (Boersma & Weenink, 2014): onset pitch value, offset pitch value, maximum pitch, and minimum pitch. No differences were found in syntactic contrast. In syntactic-semantic contrast, there was an Animacy effect when pitch values at the onset of the first noun were compared ($F(1, 29) = 6.29$, $p = .018$). The onset pitch of the animate noun was lower than the onset pitch of the inanimate noun (165.64 Hz versus 197.23 Hz). The pitch minima also differed between animacy conditions at the first noun ($F(1, 29) = 7.85$, $p = .009$). Animate nouns had an approximately 10 Hz lower minimum than inanimate nouns (142.96 Hz versus 153.32 Hz).

Finally, a syntax effect was found when the pitch minima of the second determiner were compared ($F(1, 29) = 4.94$, $p = .034$). In subject-first sentences, this peak was approximately 5 Hz lower than in object-first sentences (166.67 Hz versus 171.60 Hz).

Table 13.3.1. Analysis of variance as calculated for four parameters of Pitch of the stimuli that were used in syntactic-semantic manipulation.

		Determiner 1	**Noun 1**	**Verb**	**Determiner 2**	**Noun 2**
SYNTAX	Pitch at onset	-	-	-	-	-
	Pitch maximum	-	-	-	-	-
	Pitch minimum	-	-	-	Object-first > subject-first	-
	Pitch at offset	-	-	-	-	-
ANIMACY	Pitch at onset	-	Inanimate-first > animate-first	-	-	-
	Pitch maximum	-	-	-	-	-
	Pitch minimum	-	Inanimate-first > animate-first	-	-	-
	Pitch at offset	-	-	-	-	-

14 Appendix D: ICA-based correction of artefacts

In the current analysis of the EEG data, a semi-automatic procedure employing the independent component analysis (ICA; Bell & Sejnowski, 1995; Jung et al., 1998; Jung et al., 2000) was used for the correction of stereotyped eye and muscle artefacts. Since low-frequency contributions and non-stereotyped artefacts, such as gross head movements and drifts, negatively affect the quality of the ICA decomposition (Debener, Thorne, Schneider, & Viola, 2010), calculation of the ICA weights was performed on the high-pass filtered EEG dataset that contained only stereotyped frequent artefacts, such as vertical and horizontal eye movements as well as muscle activity.

Prior to submitting data to the ICA decomposition, non-stereotyped artefacts were excluded from the data using the following procedure. The EEG data was band-pass filtered with cutoff frequencies of 0.5 and 80 Hz (Kaiser window, transition band width 0.025 Hz, passband deviation of 0.1%) (Widmann, 2005; Widmann, Schroger, & Maess, 2015). Channels showing abnormal activity were deleted manually. The resulting data set (1) contained both stereotyped and non-stereotyped artefacts. It was submitted to regression analysis. Regression analysis was applied as a supplementary preprocessing step that allowed for detection of non-stereotyped artefacts in data (1). Regression analysis was run using four ocular electrodes: the pair E127 and E21 or the pair E126 and E14 for the vertical EOG, and E128 and E125 for the horizontal EOG. Propagation factors reflecting the relationship between EOG channels and each of the EEG channel were calculated. The propagation factors were applied to the data (1) to correct vertical eye movements. In the resulting data (2), segments that contained non-stereotyped artefactual data were detected using automatic procedures. These detected segments were removed from the original data (1). The final data (1) contained artefacts produced by eye movements but no artefacts produced by gross body and head motion.

The extended ICA algorithm (T. W. Lee, Girolami, & Sejnowski, 1999) was run on data (1) while the dimensionality of the decomposition was reduced to 30 principal dimensions using Principal Component Analysis (PCA). The calculated ICA weights were applied to the original data that was band-pass filtered between

0.3 and 20 Hz (Kaiser window, transition band width 0.15 Hz, passband deviation 0.1%). Components reflecting artifactual activity, such as eye movements, eye blinks and temporal muscle activity, were removed manually. Non-artifactual ICA components were back-projected onto the sensor array. The resulting continuous EEG data was used for further ERP analyses.

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