Processing of German Prepositions

in Adults, Typically Developing Children and Children with Cochlear Implants

Mari Chanturidze

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Chapter 1.

General Introduction

Prepositions represent a small, but central word class in many of the world's languages and a considerable amount of theoretical research has been dedicated to studying linguistic properties of these words (e.g., see Zelinsky-Wibbelt, 1993; Grießhaber, 2007; Kurzon & Adler, 2008). Despite this broad theoretical interest, experimental research studying prepositions is scarce (Littlefield, 2006/7). Collaboration between theoretical and empirical research, however, can provide deeper insight into the nature of different aspects of language and in this particular case, into the properties of prepositions. One goal of this dissertation is to initiate the first steps towards the experimental investigation of the processing of prepositions in order to find evidence for the categorization question of these words. The dissertation furthermore aims to study prepositions in typically developing (TD) children and children with cochlear implants (CI). In this introductory section, I give a brief account of the theoretical debate regarding the categorical status of prepositions. Moreover, the necessity for experimental research of prepositions in adults, TD children and children with CIs is explained.

One of the debated questions in theoretical linguistics is the categorical status of prepositions. In theories of syntactic categorization, the lexicon is divided into lexical and functional categories (Chomsky, 1993; Fukui, 1986; Fukui and Speas, 1986; Abney, 1987; Grimshaw, 1991 among others). Although lexical and functional categories can be distinguished based on a number of distinctive linguistic features, the most prominent distinction concerns the presence or absence of meaning. Representatives of the lexical category, e.g., nouns, verbs, adjectives, are generally defined as having meaning and as such, they can convey the principal meaning of a sentence. Representatives of the functional category such as determiners and complementizers, on the other hand, are virtually meaningless and fulfill a primarily structural function of combining lexical words together (Corver & Riemsdijk, 2001). The classification of prepositions in terms of the lexical/functional dichotomy has ranged from purely lexical, similar to nouns, verbs and adjectives (e.g., Jackendoff, 1977) to purely functional, similar to determiners and complementizers (e.g., Grimshaw, 1991; Baker, 2003; Botwinik-Rotem, 2004). This controversy regarding the classification of prepositions stems from the fact that in some instances, prepositions can have meaning similarly to lexical words, and in other, they can be virtually devoid of meaning similarly to functional words. Below I present examples of prepositions used as carrying meaning and prepositions used as essentially meaningless.

In example (1a) the English preposition *on* has a meaning and refers to the location of the "car". Besides location, prepositions can express other meanings. For example, *after* has temporal meaning in (1b). Prepositions such as those in example 1, that is, the ones, which convey specific meaning are referred to as *lexical prepositions* in this dissertation.

1. a. A car is parked *on* the street.
   b. We are leaving *after* 8 a.m.

In some usages, prepositions can be virtually empty of meaning as the preposition *for* in example (2). In this example, *for* is dependent on another word in the construction, namely, the verb *fall*, which selects the specific preposition (Tseng, 2000). *For* in this example has no referential meaning of its own and does not have an obvious thematic relation with its objects (Mätzig, 2009). This preposition only creates a meaningful unit together with the verb *fall*. Prepositions which are specifically selected by the verb and have no distinct referential meaning (Neeleman, 1997; Tseng, 2000) are referred to as *subcategorized* prepositions in this thesis.

2. The children will not fall *for* the same trick again.

A status of prepositions as a hybrid category has also been put forward (Zwarts, 1997, Littlefield, 2006/7). Linguistic items which cannot be straightforwardly classified as lexical or functional because they can have properties of both categories are referred to as a hybrid between lexical and functional categories. Following this argumentation, prepositions can be referred to as a hybrid category since they can be used like lexical (1) or functional (2) category words.

Although a considerable body of theoretical research has been dedicated to exploring the categorical status of prepositions (Jackendoff, 1977; Grimshaw, 1991; Baker, 2003; Zelinsky-Wibbelt, 1993; Corver & Riemsdijk, 2001; Grießhaber, 2007), experimental studies to support any of the standpoints, i.e., whether prepositions are functional, lexical or a hybrid between the two categories, is scant. Yet, experimental evidence can help elucidate the categorical status of prepositions. Previous research has revealed that brain activity associated with words belonging to lexical categories is qualitatively and quantitatively distinct from the activity associated with words belonging to functional categories (e.g., Pulvermüller, Lutzenberger & Birbaumer, 1995). Therefore, one way the categorization problem of prepositions can be investigated experimentally is by examining the brain activity to prepositions. In other words, testing whether the activity related to prepositions is more like the activity related to lexical or functional words.

Having briefly presented the questions associated with prepositions in theoretical linguistics and the necessity of experimental research regarding these words, I would like to turn to prepositions in the first language acquisition in TD children and children with CIs.

In the field of language acquisition, it is generally accepted that children acquire lexical, that is, more meaningful categories earlier than more functional, meaningless words (Radford, 1990). In this respect prepositions are a very convenient class of words to find out why there is a distinction between the acquisition of meaningful lexical and meaningless functional words. Phonologically and orthographically identical prepositions can be used both as meaningful and as virtually meaningless words. When testing the comprehension and production of phonologically identical prepositions in lexical and functional usage in children, word-length and phonological form can be controlled for. In such a way, one can examine the influence of meaning on the comprehension and production of these words and better understand whether the absence of meaning or rather the reduced (phonological) salience (shortness, lack of stress) characteristic of functional words is the main cause of the acquisition distinction found between lexical and functional words.

Not only is it interesting to study how children comprehend and produce prepositions in meaningful lexical vs. virtually meaningless functional use, but also how the developing brain treats this distinction. Comprehension and production studies, extremely valuable in their own right, show the usage of language by children as an end product of brain processing. However, what they do not show is what exactly is happening in the developing brain during the language use. This notion is particularly interesting in the case of prepositions. Very few studies have examined prepositions in children. These behavioral studies suggest that children tend to master meaningful prepositions before meaningless ones, observing that children make more omissions and incorrect substitutions of meaningless prepositions than meaningful ones (Grimm, 1975, Tomasello, 1987). Furthermore, according to these studies, in the first stage of the acquisition of prepositions children attach meaning to all types of prepositions, that is, regardless of whether they are used as meaningful (lexical) or as meaningless (subcategorized). It is only at a later stage that they discover the less meaningful usage of these words. Could it be then that the developing brain processes all prepositions qualitatively the same way, namely similarly to meaningful lexical words? In Chapter 7, this question is addressed experimentally.

Prepositions are short words, mostly mono- or bi-syllabic, and typically unstressed in the flowing speech. As a result, they are not perceptually salient. Because of these particularities, prepositions can be quite challenging to master for children with CIs, as the sound delivered by CIs is qualitatively degraded. As mentioned earlier, prepositions are very frequent and have different linguistic uses (e.g., lexical like nouns or verbs, and functional like determiners), which makes their proper mastery crucial for successful language acquisition. We know that for children with CIs words belonging to functional categories, for example determiners, represent a serious challenge in the process of language acquisition (Szagun, 2004). Studying the comprehension and production of phonologically identical prepositions in lexical and functional use can inform us about the root of the problems associated with the acquisition of functional categories by children with CIs. For instance, does the lack of meaning cause the problem? Then, it could be that children with CIs have problems when prepositions are used as functional (i.e., virtually meaningless) and not when they are used as lexical (i.e., meaningful). Or, regardless of the absence or presence of meaning, is the shortness typical of functional categories the explanation of the acquisition problems? In that case, children with CIs should find all prepositions hard to master.

Below, in section 1.1., I will present the goal and the research questions of this thesis.

1.1. Research questions

The goal of this dissertation is to accumulate experimental evidence regarding the processing of prepositions using German as a test language. Firstly, I examine the processing of prepositions using ERP methodology. This study gives insight into the categorization issue of prepositions from a neurophysiological perspective. Secondly, what this dissertation aims to explore is how TD children comprehend and produce prepositions in lexical vs. functional use, which I explored in offline comprehension and production experiments. Thirdly, an online ERP study was run with TD children to find out how the developing brain processes prepositions in lexical and functional use. Lastly, this thesis addresses prepositions during atypical language acquisition, namely, in children with CIs. To this end, comprehension and production experiments with prepositions have been conducted in this population.

Taking into account all four studies - ((1) ERP experiments with adults and (2) ERP experiment with TD children, (3) offline comprehension and production of prepositions by TD and (4) offline comprehension and production of prepositions by CI children), the research questions posed in this dissertation are the following:

- How are prepositions processed in the human brain? That is, can we find language processing evidence to resolve the problem of syntactic categorization of prepositions into lexical/functional categories?
- How are prepositions processed in the developing brain?
- Is there a difference in the comprehension and/or production of prepositions between lexical (meaningful) vs. functional (virtually meaningless) usage?
- How are prepositions in lexical and functional usage acquired by children with profound hearing impairment fitted with CIs? Does the fact that prepositions are typically not perceptually salient affect the acquisition of prepositions?

1.2. Outline of the dissertation

Four major parts can be distinguished in this dissertation: (i) psycholinguistic background, (ii) methodology, (iii) experiments and (iv) discussion and conclusion. In the background part of the thesis three chapters are presented, namely, **Chapter 1** the current chapter, which introduces the main topic and the research questions of this work. The next chapter of the background, **Chapter 2**, is dedicated to the formal analysis of the category preposition embedded in current linguistic theory. Furthermore, I review the existing literature on the acquisition of prepositions in TD children and point out the remaining questions in the field of language acquisition regarding these words. In the last section of Chapter 2, the findings regarding the language development in children with CIs are presented and the relevance of the acquisition of prepositions in this population is discussed. **Chapter 3**, which completes the background part, presents the reader with information on EEG data collection and describes the procedures for extracting ERPs from EEG data. The chapter furthermore reviews the literature on ERP research in language processing in adults and children.

The second part is comprised by **Chapter 4**, which gives a comprehensive description of the methodology used in all the experiments. Particularities, such as the exact number of participants and procedures specific to each study are given in the chapters dedicated to each study.

The third part, which is the largest part of this thesis, contains four chapters representing the four studies I conducted. In **Chapter 5** the reader can learn about the outcomes of the ERP experiment with adults addressing the issue of the categorization of prepositions. **Chapter 6** is dedicated to exploring the comprehension and production of prepositions in German-speaking TD children. The ERP study of the processing of prepositions by TD children is the topic of **Chapter 7**. The last chapter of this part,

Chapter 8, examines the comprehension and production of prepositions in children with CIs.

In the last part of this dissertation **Chapter 9**, a general discussion of the experimental findings and overall conclusion of the work is given. In addition, this chapter provides directions for further research.

Chapter 2.

Psycholinguistic background

2.1. Formal analysis of prepositions

One of the central themes of this dissertation is the issue of the syntactic categorization of prepositions. Before detailing the essence of this categorization question of prepositions, I would like to briefly address the definition of prepositions, that is, which words are typically considered as prepositions by most linguists. Researchers are not unanimous as to which linguistic elements should be referred to as prepositions. Two major standpoints exist. According to one group of researchers (e.g., Emonds, 1985; Jackendoff, 1973; Littlefield, 2006) prepositions, particles and prepositional adverbials all belong to the same category. Emonds (1985) and Jackendoff (1973) suggest that particles and prepositional adverbials are intransitive prepositions. This theoretical assumption is based on such observations as that particles and prepositional adverbials share their phonological form as well as semantic meaning with prepositions (Mätzig, 2009). The other group advocates classifying prepositions, particles and prepositional adverbials into separate categories (e.g., Bolinger, 1971; Fraser, 1976; Baker 1995). Among others, this viewpoint is based on the observation that in the case of particles and prepositional adverbials the prepositional element may precede *and* follow the object. In contrast, in the case of prepositions, the order of prepositions and object is fixed (Corver & Riemsdijk, 2001). The typical structure for prepositional phrase (PP) is PP →P – DP (at least for German and English), whereas particles are prepositional adverbials that do not take arguments (e.g., Bolinger, 1971; van Riemsdijk, 1978). Whether particles and prepositional adverbials should be classified as prepositions remains unresolved in the current linguistic literature (Littlefield, 2006). However, this debate is not the focus of the dissertation and, hence, is not discussed in further detail.

The definition of prepositions adopted in this thesis is the one traditionally taken to be prototypical of the category by the majority of linguists (van Riemsdijk, 1978; Littelfield, 2006; Wiese, 2000; Zwarts, 1997; Eisenberg, 2006; Grießhaber, 2007). In many languages, the relationships between objects and events in space and time are expressed by adpositions. There are adpositions that precede their complements (e.g., *around* the garden), adpositions that follow their complements (e.g., three weeks *ago*) and adpositions that enclose their complement (e.g., *from* then *on*) (Mätzig, 2009). In this dissertation, prepositions are the type of adpositions that precede their nominal complement and license case on it.

As introduced briefly in the previous chapter, theoretical research is not unanimous regarding the syntactic classification of prepositions into lexical and functional categories (Littlefield, 2006; Cover & Van Riemsdijk, 2001). The classification of prepositions in terms of the lexical/functional divide has ranged from purely lexical, similar to nouns, verbs and adjectives (e.g., Jackendoff, 1977) to purely functional, similar to determiners and complementizers (Grimshaw, 1991; Baker, 2003; Botwinik-Rotem, 2004). The status of prepositions as a non-uniform, hybrid between lexical and functional categories has also been put forward (Zwarts, 1997; Littlefield, 2006; Corver & van Riemsdijk, 2001; Rauh, 1993; Mätzig, 2009). The hybrid approach argues that the distinction lexical vs. functional should be made *within* the category preposition, i.e., some prepositions can be categorized as lexical, whereas others should be categorized as functional, depending on how they are used. Before turning to specific examples, a brief note on the terminology and classification of prepositions is due.

Independent of the lexical/functional divide for the word class as a whole, prepositions have been divided into several types depending on their linguistic properties. Broadly speaking, three groups of prepositions are identified, namely, *lexical* (see examples 3 & 4 below for a preposition used for location and time in German and English), structural, called *subcategorized* in this dissertation (5) also referred to as grammaticized, collocative, non-lexical, dependent or governing, and *syntactic* (6) such as possessive *of*, passive *by*, German *von* both for possessive and passive, or dative *to* German *zu*[1] (for a detailed review see Mätzig, 2009).

3. a. Nina leg-te das Buch *auf/unter/neben* den Tisch.
Nina.NOM.SG. put-PST.SG the.NOM.SG. book.NOM.SG. on/under/next to the.ACC.SG. table.ACC.SG.
b. "Nina put the book *on/under/next to* [$_{DP}$the table]."

4. a. Die Sitzung finde-t *am/nach /vor* Montag statt.
the.NOM.SG. meeting.NOM.SG. find-PRS.SG on/after/before Monday.DAT.SG. place.DAT.SG.
b. "The meeting takes place *on/after/before* [$_{DP}$Monday]."

5. a. Der Bäcker frag-t *nach/*mit/*an* einem Apfel.
the.NOM.SG. baker.NOM.SG. ask-PRS.3SG. after/with/on a.DAT.SG. apple.DAT.SG.
"The baker is asking *for/*with/*on* an apple."

1 In English syntactic *for* is also used syntactically in structures such as "What I want is *for* him to meet the deadline" Lindstromberg, 2010.

b. Everyone picked *on/*in/*under*[2] [$_{DP}$the new student]. (Tseng, 2000)

6. a. Die jüng-er-en Kind-er werden *von* ihren Lehrer-n unterstütz-t.
the.NOM.PL young-COMP-PL.NOM child-PL.NOM be.PRS.3PL. From their.DAT.3PL teacher-PL.DAT. support-PST.PTCP.
b. "The younger children are assisted *by* their teachers."

I will address only *lexical* and *subcategorized* prepositions in German in this thesis. *Syntactic* prepositions are not examined in this work primarily because of methodological reasons. In the experimental design employed in the studies presented here, a number of phonologically and orthographically identical prepositions that can be used either as lexical or as subcategorized are tested. This design specification is not possible to apply to syntactic prepositions, because there are only very few of them (von, zu), which makes them difficult to group.

Several linguistic properties have been distinguished to classify different syntactic word classes (e.g., nouns, verbs, determiners, etc.) into lexical or functional. The most commonly addressed distinctive property in terms of this categorization is the absence or presence of meaning. Lexical words are generally defined as having relatively detailed meaning and as such they carry the principal message of the sentence. Functional words, on the other hand, lack semantic content and fulfill the primarily syntactic function of connecting the lexical words (Corver & Riemsdijk, 2001). Besides the presence or absence of semantic meaning, several other characteristics for each category have been discussed in the literature (e.g., Rauh, 1993; Mätzig, 2009). For instance, lexical words belong to the open classes of words meaning that new members can freely enter this class, whereas functional words have a fixed inventory and few other members are ever added to them. Functional words are generally morphologically and phonologically dependent. They are typically unstressed. Furthermore, lexical words can determine linguistic properties of their argument both on a semantic *and* on a syntactic level (Rauh, 1993). At the semantic level, lexical categories determine thematic roles (agent, patient, goal, etc.) of their arguments (Mätzig, 2009). For example, in (7a), the verb *meet* assigns two thematic roles to its arguments, namely, agent (*John*) and patient (*his teacher*).

7. a. John met [$_{DP}$his teacher].

2 *at* is possible with a slight change of meaning expressing criticizing someone rather than bothering someone as with *on*.

b. John met *[$_{CP}$that his teacher was good].

At the syntactic level, lexical words determine the syntactic nature of their arguments (Rauh, 1993). In (7a) the verb *meet* determines the syntactic type of its argument by selecting a determiner phrase (DP). In (7b) this verb does not select for a complementizer phrase (CP).

In contrast, functional elements determine *only* morpho-syntactic features of the arguments (Rauh, 1993). For instance, auxiliaries (e.g., *will, have, be*) or tense inflections (e.g., *-ed, -s*), which belong to the functional category, can impose morpho-syntactic restrictions to their arguments, but cannot assign thematic roles (Adger, 2003). In (8a) the auxiliary *is* has a particular morphological effect on the verb following it, namely, the verb has to be accompanied by the present participle ending in *-ing*. Similarly to other functional elements, the auxiliary *is* cannot determine the thematic role of its arguments. Instead, the verb *to mend* - a lexical category - assigns the thematic roles of agent to *Mary* and patient to *the torn dress* (8a). To illustrate, if we change the lexical verb but leave the specific auxiliary *is* in place, the thematic roles will change according to the lexical verb *to get* (8b). Namely, *Mary* now is assigned the thematic role of a goal instead of agent.

8. a. Mary is [$_{VP}$mending the torn dress].
   b. Mary is getting the torn dress.

Turning back to prepositions as a hybrid between lexical and functional categories, the idea here is that the difference between lexical and functional elements is not absolute, i.e., not all elements can be classified as either lexical or functional. In some uses, prepositions can be considered a functional category, e.g., subcategorized prepositions, and in other uses a lexical category, e.g., lexical prepositions (see examples 3-5 above; cf. Zwarts, 1997; Littlefield, 2006; Rauh, 1993).

Let us now consider the properties of the lexical/functional divide as applied to prepositions. Prepositions, even ones that have the same phonetic and orthographic form, carry different linguistic properties. In the German example (3a) and English (3b) above, *auf* and *on,* respectively, express location, i.e., these prepositions are semantically loaded. Not only do such prepositions carry semantic meaning, but they are also polysemous: German *an/am*[3] in (4a) and English *on* in (4b) above convey temporal meaning. This feature, namely having relatively specific/detailed semantics prompted theoreticians to suggest that prepositions such as *on* in (3 & 4) belong to a

3 *am* in *am Montag* is used to convey the meaning of *montags*, i.e, on Mondays.

lexical category (similar to nouns, verbs, etc.; see Littlefield, 2006; Zwarts, 1997; Rauh, 1993). *Nach* (after) in German (5a) and *on* in English (5b), however, are semantically virtually empty – they have no specific referential meaning; the preposition is directly subcategorized (through idiomatic selection) by the verb *fragt* (asks) and *pick*, respectively (Mätzig, 2009; Tseng, 2000). Since functional categories in general are semantically relatively empty and are dependent on the elements they accompany, prepositions like in (5) have been suggested to belong to a functional category (such as determiners, complementizers) (Corver & Van Riemsdijk, 2001). The same holds for syntactic prepositions such as German *von* (by) and English *by* in (6a & b).

Furthermore, *auf* in (3a) and *on* in (3b) can be replaced by virtually any (locative) preposition, while the sentence still remains acceptable (Mätzig, 2009). In other words, the preposition here does not have a strong bond with the preceding verb; the specific preposition is independent of the verb and does not create unity between itself and the preceding verb.

Similarly to lexical categories, lexical prepositions assign thematic roles to their arguments such as location (e.g., *in/on/at/under/the roof*), goal (e.g., *We walked to the forest*), source (e.g., *she is from New York*), path (*they drove through the city*), and instrumental (*open the door with this key*; cf. Littlefield, 2006; Mätzig, 2009). Together with thematic role assignment, a lexical preposition determines the syntactic type of its argument as illustrated in the example (7) above. Although thematic role assignment by lexical prepositions is clear, the situation is controversial for subcategorized prepositions. Some authors suggest that subcategorized prepositions do not determine the thematic role of their arguments; instead, the verb selecting the preposition does (Littlefield, 2006; Tseng, 2002), whereas others, for example, Neeleman (1997), suggest that subcategorized prepositions are idiomatically selected by the verb in order to assign a thematic role to their complements which also matches the internal thematic role of the verb.

There are properties which are shared by lexical and subcategorized prepositions such as case assignment (Mätzig, 2009). According to Haider (2012), in German prepositions can license either accusative and/or dative, or genitive, but never nominative. Another shared property is that both types of prepositions are closed class words, i.e., they have a fixed inventory and few other members are ever added to this class – a property associated which functional categories (Corver & Van Riemsdijk, 2001). A short summary of the properties of each type of preposition is given in Table 2.1 below.

Table 2.1. Characteristic properties of lexical and subcategorized prepositions.

Properties	Lexical	Subcategorized
Relatively specific semantic meaning	Yes	No (non-conceptual meaning)
Dependence on Verb	No	Yes
Class membership[4]	Closed	Closed
Thematic role assignment	Yes	Not clear/controversial
Case marking	Yes	Yes

To summarize, judging from the linguistic properties of lexical and subcategorized prepositions (Table 2.1), I assume that the former is more like lexical category (verbs, adjectives, etc.) and the latter more like functional category words (determiners, inflection, complementizers, etc.), i.e., they play a primarily syntactic role in language.

2.2. Prepositions in first language acquisition

Prepositions represent an intriguing class of words to study lexical development in children. The reason why these words can be so interesting for the language acquisition field is that, as already discussed in the previous section, not only are prepositions very frequent (Fang, 2000; Grießhaber, 2007), but depending on their usage, they can also exhibit properties of both lexical and functional categories (e.g., Rauh, 1993; Littlefield, 2006). Despite having such interesting linguistic features, prepositions have been largely ignored in studies on language acquisition.

In language acquisition research, there is evidence that lexical categories (e.g., nouns, verbs) are typically acquired first, whereas functional categories (e.g., determiners, complementizers) emerge later in children's language (Radford, 1990). From the perspective of lexical development in children, prepositions represent an interesting category to study the acquisition of words with lexical and functional properties while keeping the phonological and orthographical material constant. This way, one can examine in how far lexical and functional properties play a role in the development of the lexicon when word length and phonological material is accounted for. At this point, little is known about the comprehension and production of prepositions in TD children in German (or other languages).

There are only a few studies concerning prepositions based on spontaneous

4 According to some researchers, prepositions cannot be classed strictly as closed. As new prepositions can enter the lexicon. However, prepositions do not have regular worldbuilding properties such as, e.g., nouns (e.g., Eisenberg, 2013).

speech production in German and other languages, mostly in English (Tomasello, 1987; Rice, 2003; Littlefield, 2005; Rice, 1999; Alexaki et. al., 2009; Morgenstern & Sekali, 2009). Tomasello (1987) documented one child's earliest use of prepositions during her second year of life. This spontaneous speech study found that spatial oppositions of lexical prepositions such as *up-down*, *in-out* and *over-under* were learned first followed by prepositions in more functional usage. Rice (1999) conducted a corpus study of 32 English-speaking children's first usage of the prepositions *to* and *for* (which have similar properties semantically and grammatically). She concluded that frequency of use in the children's linguistic environment and co-occurrence with favored verbs or other common expressions proved to be the major determinant of early production as opposed to their linguistic usage (i.e., lexical vs. functional). In another study, Rice (2003) examined nine prepositions from the longitudinal data obtained from the CHILDES corpus for two English-speaking children (1;3 to 5;0 years). The author observed that the emergence of a specific preposition and its subsequent usage is motivated by frequency of exposure and favorite expressions, rather than just by the fact that in some usages prepositions convey a certain meaning, which can make them more salient for children to acquire. Littlefield (2005) studied prepositions in two children (1;2 – 5;0 years) in the CHILDES database as well. She compared the acquisition of lexical prepositions as opposed to the syntactic preposition *of*. The author observed that both children showed a steady increase in their use of lexical prepositions over time, whereas the functional preposition entered their spontaneous speech after mastering (some of the) lexical usage of prepositions.

A relatively comprehensive study on the acquisition of German prepositions dating back to 1975 by Grimm, did study prepositions in different usages, albeit in spontaneous production only, similarly to the studies presented above. The study showed that lexical prepositions are acquired first, gradually followed by subcategorized prepositions. According to this study, children use incorrect prepositions in their functional use up to seven years of age. In her reaction time study of German lexical and subcategorized prepositions, Friederici (1983) found that eight- and nine-year-old children found prepositions in their functional usage more difficult than prepositions loaded with meaning (i.e., lexical usage); however, by the age of ten and eleven this difference between different types of prepositions had disappeared. Despite their important implications for the development of prepositions and first language acquisition in general, the studies reviewed here have certain limitations. Except for Friederici (1983), all of them are corpus studies of spontaneous speech. Accordingly, they are informative only about the production but not the comprehension of prepositions in children. Moreover, spontaneous production is not controlled for elicitation of specific linguistic structures, which limits the variability and hence generalizability of the results. In such a setting, children could apply the strategy of using prepositions they find easy or are sure of. Another limitation of most of these works is that they are case reports with only one or two child-participants, or study very few prepositions. Therefore, the acquisition of prepositions in their wider range and functions (e.g., lexical and functional) both in comprehension and production in children of different ages is not fully captured.

2.3. Language in cochlear implanted children and the relevance of the acquisition of prepositions

In the section above, I discussed the significance of research on the acquisition of prepositions in TD children. In the present section, I will address the issue of the acquisition of prepositions in atypical development, specifically in children with hearing loss who wear CIs. Successful language acquisition presupposes efficient auditory functioning (Mueller, Friederici & Männel, 2012), but because of their hearing loss, these children's language perception is degraded. Therefore, prepositions, being not salient in the flow of speech, can be potentially problematic for these children.

Candidates for cochlear implantation are children with severe to profound sensorineural hearing loss (SNHL) (i.e., pure-tone average ≥ 70 dB hearing loss)[5]. SNHL occurs in the cochlea (the inner ear) and has a profound effect on decoding the speech signal (Ainsworth et al., 2004). Cochlear implantation involves placing electrodes directly into the cochlea. These electrodes bypass the malfunctioning inner ear and directly stimulate the auditory nerve by converting sounds into electrical signals (e.g., Zeng et al., 2008). CIs nowadays use between 12 and 24 electrodes that span the frequency range between approximately 100 and 8000 Hz (Giezen, 2011). Once children with SNHL start using CIs, they tune into the sound system of the input language. Although CIs can restore hearing (Schauwers, Gillis & Govaerts, 2005), they fail to transmit all the specifications of speech signal and therefore provide a coarse spectro-temporal representation of information of the speech signal (Le Normand, Ouellet, & Cohen, 2003; Ainsworth, Popper & Fay, 2004). The spectral signals delivered

5 Hearing is measured in decibels (dB) with the threshold of 0 dB for each frequency denoting the value at which normal young adults perceive a tone burst of a given intensity and frequency 50% of the time. A child's hearing acuity is classed as normal if it is within 20 dB of these defined thresholds. Severity of hearing loss is graded as mild (20–40 dB), moderate (41–55 dB), moderately severe (56–70 dB), severe (71–90 dB), or profound (>90 dB), and the frequency of hearing loss is designated as low (>500 Hz), middle (501–2000 Hz), or high (>2000 Hz) (Smith, Bale &White, 2005 p. 879).

to the brain by CIs are qualitatively degraded (Drennan & Rubinstein 2008). Moreover, the auditory deprivation during the period before implantation can adversely affect development of the auditory-neural pathways resulting in further poorer processing of sounds (Kral, Kronenberger, Pisoni, & O'Donoghue, 2016; Moore & Linthicum, 2007). Not surprisingly, this experience of degraded language perception affects acquisition in these children (Schouwenaars et al., 2019).

A general tendency in research on language abilities of CI children is that although the lexicon is relatively spared, these children often suffer from a lack of knowledge regarding morphological and syntactic rules (Caselli et al., 2012; Geers, Nicholas, & Sedey, 2003; Nikolopoulos, Dyar, Achbold & O'Donoghue, 2004). Studies find asymmetries in the acquisition of lexical, i.e., meaningful (nouns, adjectives) and functional, i.e., less meaningful words (determiners, complementizers) by children with CIs (Le Normand et al., 2003; Szagun, 2000). For instance, while the acquisition of nouns by children with CIs is similar to that of TD peers, they experience serious difficulties when it comes to the acquisition of bound and free-standing morphemes and determiners (Le Normand et al., 2003; Szagun, 2000 & 2004; Hammer, 2014). In comparison to their TD peers, children with CIs produce fewer bound morphemes (Geers, 2004; Nicholas and Geers, 2007) and often omit free-standing morphemes (Caselli et al., 2012). These difficulties can be due to the suboptimal auditory input that children with CIs receive, which especially affects the acquisition of linguistic elements with low perceptual salience, that is elements that are short in length, typically unstressed or hard to distinguish from one another (e.g., homonyms) (Szagun, 2004; Hammer et al., 2014). However, a lack of perceptual salience alone cannot explain why children experience deficits regarding functional words. In addition to low salience, functional words have non-conceptual meaning and fulfill essentially a grammatical function of gluing the meaningful words together (Corver & Riemsdijk, 2001). Thus, when acquiring functional words children have to deal with not only vagueness of meaning, but also with the abstract structural functions of these words in sentences. Studying the prepositions distinct in usage (lexical vs. functional), but phonologically identical, thus controlling for the phonological form, can be especially informative about the role of lexical and functional properties of words in the process of language acquisition in children with CIs.

Having discussed challenges that children with CIs face in the process of language acquisition, it should also be mentioned that CI users still profit substantially from their implants despite the degraded auditory input (Krueger et al., 2008). Importantly though, there are large individual differences with respect to language development in children with CIs (e.g., for German, Szagun 2001; for Dutch, Giezen, 2011; Gillis, Schauwers, & Govaerts, 2002; for French, Duchesne, Sutton, & Bergeron, 2009; Le Normand, Ouellet, & Cohen, 2003). These individual differences in language development are partially explained with respect to the age of CI implantation and hearing age, i.e., the chronological age minus the age at implantation. It has been argued that the earlier children receive their implants, the better their hearing and language outcomes will be (o.a., Harrison, Gordon, & Mount, 2005; Sharma, Dorman, & Spahr, 2002; Lesinski-Schiedat, Illg, Heermann, Bertram Lenarz 2006; Tomblin, Barker, Spencer, Zhang & Gantz, 2005).

In addition to age of implantation, working memory has also been associated with language outcomes in children with CIs (and TD children) (Harris et al., 2013; Kronenberger et al., 2011; Pisoni, Kronenberger, Roman, & Geers, 2011; Kral, Kronenberger, Pisoni, O'Donoghue, 2016; Schouwenaars et al., 2019). Working memory is a mental system responsible for temporary storage and simultaneous manipulation of information from different sensory domains and it is involved in complex mental processes such as language comprehension, reasoning and problem solving (Baddeley, 1986; Baddeley & Hitch, 1974). In studies with children, significant involvement of working memory in linguistic computations has been evidenced (e.g., Roberts, Marinis, Felser, & Clahsen, 2007). It is widely accepted that working memory capacities in children with CIs can be compromised (Kronenberger, Beer, Castellanos, Pisoni, & Miyamoto, 2014). Some suggest that auditory deprivation has widespread effects on the development of the brain. After auditory sensory deprivation, the brain's effective connectivity is changed in the systems serving higher order neurocognitive functions (Pisoni, Conway, Kronenberger, Henning, & Anaya, 2012; Giraud & Lee, 2007; Kral et al., 2016). In addition to auditory functioning, language also plays a crucial role in the development of working memory (Zelazo, 2000; Frye, Zelazo & Palfai, 1995; Figueras et al., 2008). However, at this point it is not completely straightforward whether atypical language development negatively affects working memory capacities in these children, or the other way around, i.e., that reduced working memory capacity hinders development of language. Typically, children with CIs score lower on working memory tasks than TD children do (van Wieringen & Wouters, 2014; Cleary, Pisoni & Geers, 2001). When it comes to input modality (i.e., visual or verbal) of working memory tasks, research is not unanimous. While there is evidence that children with CIs lag behind their TD peers both on verbal *and* spatial-visual working memory (Cleary, Pisoni & Geers, 2001; Pisoni & Cleary, 2003), some findings demonstrate that in contrast to verbal working memory, on visual working memory tasks children with CIs are as good as their TD peers (e.g., Lyxell et al., 2008; Wass et al, 2008).

As for prepositions in children with CIs (Chapter 8), although there are no published studies about different types of prepositions in children with CIs, prepositions have been briefly mentioned as part of general lexical development in this population. According to Lichtenstein (1998), children with CIs make errors and omissions associated with the use of functional words such as articles, prepositions, copulas and pronouns (Lichtenstein, 1998; Szagun, 2000). Le Normand, Ouellet, & Cohen (2003) studied the production of lexical categories longitudinally in French-speaking children with CIs and found that these children had problems with processing locative adverbs, prepositions, pronouns, and verbs (infinitive verb, modal, and modal lexical). Besides, in personal discussions with language clinicians working with children wearing CIs, prepositions were characterized as often compromised in these children. Although all of these hint to the fact that children with CIs could be experiencing problems with prepositions, it is not clear whether difficulties regarding these words persist in their different linguistic functions and, if indeed problematic, how these difficulties develop over time: does mastery of prepositions improve or does it stay impaired through time?

As stated in the beginning of this chapter, prepositions are very frequent in language (Fang 2000) and carry important semantic and syntactic roles. Therefore, studying prepositions in children fitted with CIs can help us better understand the effects of the CI and hearing impairment on language development.

Chapter 3.

Electroencephalography and its application in language research

3.1. From electroencephalography to Event-related Potentials (ERPs)

This section of the dissertation is dedicated to introducing the reader to electroencephalography (EEG) and its application in linguistic research. Two studies, presented in chapters 5 and 7, use the method of EEG to study the neural underpinnings of the processing of prepositions.

In humans, EEG was first recorded by the German psychiatrist Hans Berger (1873–1941) (Bornkessel-Schlesewsky & Schlesewsky, 2009). He reported that it is possible to measure the electrical activity of the human brain by placing electrodes on the scalp. This electrical activity of the brain, represented as voltage fluctuations across time, is called EEG (Boudewyn, 2015). EEG is recorded from the scalp surface and it is a completely non-invasive procedure that can be applied repeatedly with essentially no risk or limitation. Hence, it is widely used to investigate the brain organization of cognitive processes such as perception, memory, attention, language, and emotion (Teplan, 2002).

Raw continuous EEG recordings represent a mixture of hundreds of different neural activities in the brain. Therefore, it is very difficult to use raw EEG to study specific voltage fluctuations related to a stimulus of interest, which is the focus of neurocognitive research. The electrical signal synchronized to a cognitive process is covered up in unrelated electrical noise. It is possible, however, to extract these stimulus-related responses from the overall EEG by means of an averaging technique and time-locking to the stimulus onset. These stimulus-related responses are referred to as event-related potentials, or ERPs (Luck, 2005).

ERPs are significant voltage fluctuations resulting from stimulus-related neuronal activity. The amplitudes of ERP components are often much smaller than spontaneous ongoing EEG activity. For example, voltage fluctuations induced by language stimuli are approx. 2–8 μV, while spontaneous electrical activity of the brain is approx. 10–100 μV. This means that sufficient stimuli must be presented per recording for the signal-to-noise ratio to reach acceptable levels (Bornkessel-Schlesewsky & Schlesewsky, 2009).

To extract ERPs from ongoing EEG, signal averaging is used. During the averaging process, first several trials time-locked to a stimulus of interest (e.g., a word), or epochs, are extracted from the ongoing EEG. The epochs then are layered over each other and averaged in a point-by-point manner. Since the voltage fluctuations related to the critical stimulus are normally the same for all trials/epochs, while the unrelated random activity, or noise, differs from trial to trial, the latter should get averaged out leaving the event-related brain potentials (Luck, 2005). Figure 3.1 illustrates this signal averaging process.

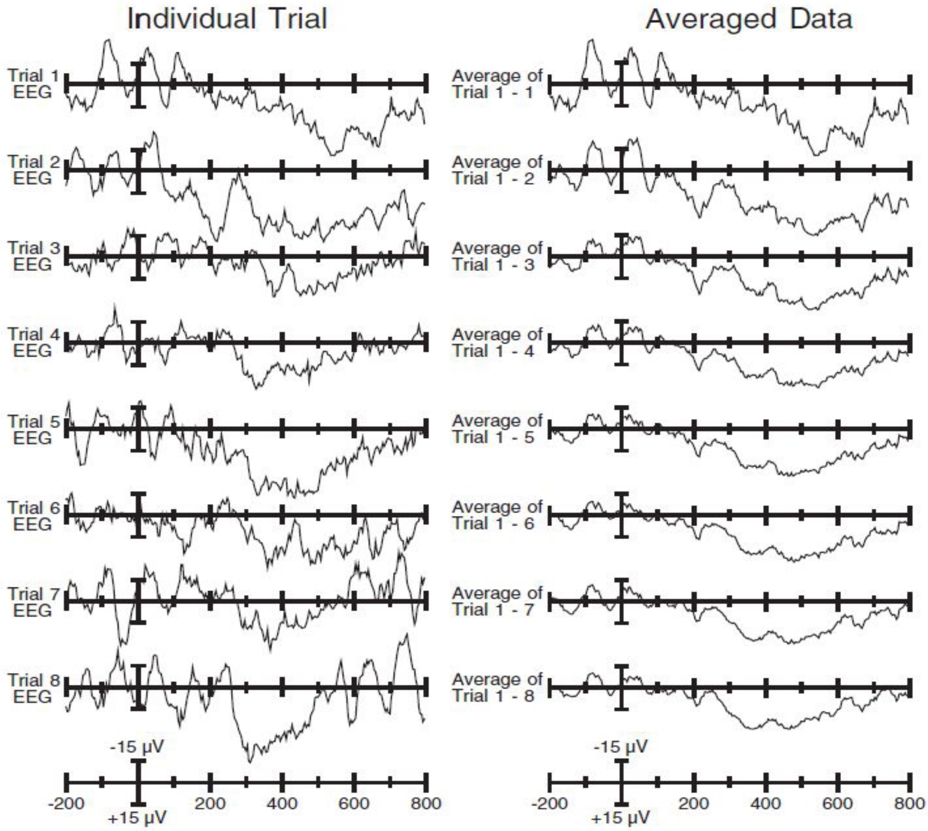


Figure 3.1. Example of signal-averaging process. The left column shows parts of EEG for each of several trials, time-locked to stimulus onset. The right column shows the effects of averaging of these EEG segments (source: Luck, 2005).

ERPs describe the electrical activity of the brain according to four parameters, namely, latency, polarity, topography and amplitude (Bornkessel-Schlesewsky & Schlesewsky, 2009). *Latency* refers to the time point relative to critical stimulus onset at which the change in the potential is observed. The peak latency and onset latency are distinguished. The former refers to the timing of the amplitude maximum, and the latter to the time point at which the critical condition starts to diverge from the control condition. Latency is typically measured in milliseconds (ms). *Polarity* of an effect shows whether the potential change in the critical condition is positive or negative relative to the control condition. ERP component names often contain letters "N" for negativity and "P" indicating positive polarity. The distribution of an effect across electrodes on the scalp is referred to as *scalp distribution or topography*. As the changes at the surface of the scalp are not restricted to single electrodes, researchers usually define topography in terms of groups of electrodes, also known as regions of interest or ROIs. *Amplitude*, which is measured in microvolts μV, shows how "strong" an effect is. Unlike the three parameters presented above, amplitude does not define an ERP component as it reflects quantitative changes in qualitatively similar activities (Bornkessel-Schlesewsky & Schlesewsky, 2009).

When discussing ERPs, it is important to clarify the distinction between so called ERP "components" and ERP "effects". Different components can be interpreted as reflecting distinct cognitive processes elicited under certain experimental conditions or paradigms. For example, while one component can be elicited by lexical-semantic processing, another can be observed in various oddball paradigms in response to deviant (infrequent) stimuli presented in a series of standard (frequent) stimuli. A particular component, let us say the one observed during lexical-semantic processing, can be modulated by word frequency (see Kutas & Federmeier 2000). Although the processing of frequent and infrequent words can both elicit the same component (because the underlying cognitive processing is the same), for infrequent words larger amplitude is typically observed than for frequent words. Such difference within ERP components is referred to as an ERP effect. ERP effects are not assessed with respect to the coordinate system (i.e., in absolute terms). Hence, when talking about ''negative'' polarity of an effect one means that it is a more negative-going waveform in comparison to the control, even though in absolute terms the mean voltage may be positive.

In a typical experiment (Figure 3.2), participants wear special EEG caps. The electrodes attached to this cap read the brain signal. While attending to the task participants' ongoing EEG signal is recorded using special software, digitally filtered and amplified. At the same time, the stimulus presentation computer is sending out triggers, stimuli onset points, to the EEG recording computer which are saved together with the EEG signal. After the recording, the raw EEG signal is filtered offline and the time-locked epochs triggered by the onset of each stimulus are extracted. Filtering removes certain frequencies from the EEG signal that are considerably different from the frequencies contributing to the ERP waveform (Männel, 2009). To increase the signal-to-noise ratio further, epochs (or trials) which are contaminated with noise artifacts are rejected and/or the noise in the signal is attenuated. Rejecting epochs involves completely removing contaminated parts of the signal, while during the attenuation process specific components of the signal which contribute to the noise are deleted. Such components are stereotypical artifices such as eye blinks – large amplitude deflections – and muscle, heartbeat, etc. Subsequently, a sufficient number of artifact-free trials are averaged to obtain a high signal-to-noise-ratio. Ideally, the preprocessing steps and averaging produce a smooth curve of changes in electrical activity that represents the processing of a stimulus over time, i.e., the event-related brain potential (Männel, 2009).

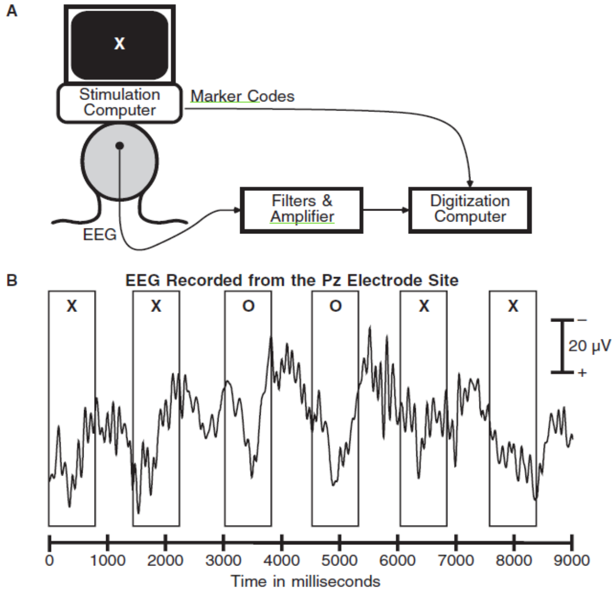


Figure 3.2. An example ERP experiment. The subject (panel A) views frequent Xs and infrequent Os (panel B) presented on a computer monitor while the EEG is recorded from a midline electrode site (source: Luck, 2005).

In language research the application of ERP method has considerably advanced our understanding of the neural underpinnings of different linguistic aspects. One important advantage of using ERP methodology in language research is that we can measure ERPs to any and all words in the sentence without interrupting the language comprehender with a task. Tasks, e.g., a sentence judgements task, can be (as has often been the practice) included *after* presentation of the entire language stimulus is completed (Swaab et al., 2012).

An especially relevant finding for the research presented in this dissertation is the ERP evidence for the separation between lexial-semantic and syntactic processing. The ERP component correlated with the processing of semantic information is the N400 – a negatively distributed waveform which peaks at around 400 ms after the onset of the critical stimulus (visual or auditory presentation) (see among many others Kutas & Hillyard, 1980; Friederici, 2004; Friederici, 2011). The N400 has been observed in processing difficulties associated with lexical-semantic integration (e.g., Friederici, Hahne, & Saddy, 2002; Kutas & Hillyard, 1980; Friederici, 2011). For instance, in (9) the sentence either ends in a word that fits the semantic expectation created by the sentence context – *garden* – or in a word that does not fit this expectation by ending with *sky*.

9. I planted string beans in my garden/*sky. (Kutas & Hillyard, 1980)

Clearly, *sky* in (9) violates the semantic expectations of the sentence. In cases like this an N400 is elicited. However, as for example Hagoort and Brown (1994) have observed, the N400 effect does not depend on a semantic violation *per se*. Even more subtle differences in semantic expectancy, such as between *mouth* and *pocket* in (10), where both words are possible but *mouth* is the preferred continuation and *pocket* merely less expected, can modulate the N400 amplitude.

10. Jenny put the sweet in her mouth/pocket after the lesson. (Hagoort & Brown, 1994).

Not only the semantic fit, but also the presentation modality can influence the characteristics of N400. A number of studies have found the effect to have earlier onset latencies in auditory than in visual presentation and to last longer (Holcomb & Neville 1990, 1991; Hagoort, 2008; Kutas et al., 2011). Furthermore, studies of speech processing (e.g., auditory presented sentences) have found that in contrast to a visual N400, an auditory N400 effect is not always a monophasic negative shift and can actually be composed of two separate negative polarity components/peaks of which only the second one is argued to reflect the N400 (Connolly et al, 1990; Hagoort & Brown, 2000; Van den Brink et al., 2001). The first negative shift is referred to as the N200 or the phonological mismatch negativity (PMN) and reflects acoustic/phonological word processing (Connolly & Phillips, 1994), a process that precedes the semantic integration process. As for the topography of the N400, Hagoort and Brown (2000) reported that unlike the prototypical visual N400 effect, which tends to be slightly larger over the right hemisphere, the auditory N400 in their experiments was either symmetrical or larger over the left than the right hemisphere. Similar to the effect for the visual modality, the auditory N400 effect had a clear posterior distribution.

The situation is somewhat more complex for the ERP pattern associated with morpho-syntactic processing. One ERP component that has been elicited for morpho-syntactical processing difficulties is the P600 (or late positive) – a positive deflection peaking roughly between 500 and 900 ms after stimulus onset (e.g., Osterhout et al., 1994; Kaan, 2007; Kaan & Swaab, 2003; Friederici, 2011). This late positive component has been observed in response to processing of syntax-related violations

(11) or structural ambiguities (12), which necessitate syntactic mechanisms such as reanalysis, repair, or integration in complex structures (for a review see Bornkessel-Schlesewsky & Schlesewsky, 2009).

11. The man in the restaurant doesn't like the hamburger that is/*are on his plate. (Kaan & Swaab, 2003).
12. The lawyer charged the defendant was lying. (Osterhout et al., 1994).

The P600 has been found for morpho-syntactic processing of agreement violations (number, gender, person) (Hagoort, Brown, and Groothusen, 1993a; Molinaro et al. 2011) as in (11) and (13). Hagoort et al. (1993a) observed a P600 for processing of number agreement mismatch between subject and verb of sentences in Dutch (13.

13. *Het	verwende		kind	gooien	het
speelgoed	op	de	grond. (Hagoort et al., 1993a).		
the	spoilt		child-SG.	throw-PL.	the
toy	on	the	ground		

"*The spoilt child throw the toys on the ground."

The P600 component is observed in response to (morpho)syntactic violations either as a monophasic component or following an (early) left anterior negativity ((E)LAN). An ELAN is observed between 120 and 200 ms following the critical stimulus onset and is taken to reflect initial syntactic structure building processes, whereas a LAN is observed in the time window between 300 and 500 ms after the stimulus, has been elicited in response to syntactic features that mark the grammatical relation between arguments and verb (Friederici, 2011, but see Steinhauer and Drury, 2012 for discussion). For example, a biphasic LAN-P600 ERP pattern as a result of processing agreement violations has been reported by a number of studies (see for a review Molinaro et al, 2011). Molinaro et al. (2008) studied the processing of gender agreement violation between determiner and noun in Italian. As a result of the gender disagreement/violation both a LAN and a P600 were elicited on the noun in this study. Thus, ELAN/LAN are other ERP components that have been correlated with syntactic processing. The major difference between the late positive component (P600) and relatively early anterior negativities (ELAN/LAN) is that while the anterior negativities are only elicited when processing outright violations, the P600 is observed when processing outright violations *and* when processing violations of structural preferences (Friederici, 2001).

The P600 (or late positivity) is not restricted to morpho-syntactic processing only, as it has even been associated with semantic or thematic processing difficulties ("semantic P600") (e.g., Kim & Osterhout, 2005; Kuperberg et al., 2007; van Herten et al., 2005; for a detailed discussion regarding the interpretation of "semantic" positivities see Bornkessel-Schlesewsky & Schlesewsky, 2009; Kuperberg et al. 2007; Brouwer et al. 2012). Roehm et al. (2007) found a biphasic N400/P600 pattern in relation to the processing of syntactically valid sentences such as *The opposite of black is nice*. In this sentence, the prediction for an antonym (*white*) is not fulfilled. The authors interpreted the late positivity as a correlate of a global evaluation of the sentence's well-formedness.

Hoeks et al. (2004) also reported a biphasic N400/P600 effect in relation to syntactically correct Dutch sentences such as in (14).

14. De speer heeft de atleten opgesomd
    the javelin-SG. have-SG. the athlete-PL. summarized
    "The javelin summarized the athletes."

In (14) the words *javelin*, *athletes*, and *summarized* do not fit together semantically (meaningfully), while the sentence is syntactically valid. The authors suggested that the P600 to these sentences can indicate processing problems originating from semantic or thematic incongruities.

In sum, substantial evidence has accumulated in language related electrophysiological research concerning the processing of semantic and morpho-syntactic difficulties. This ERP evidence can serve as the basis for examining whether there is a distinction in the processing of prepositions in lexical and functional use. I will present the ERP study on the processing of lexical and functional prepositions in Chapter 5. The application of ERP methodology to study the processing of prepositions in lexical and functional use in the developing brain (in children) is presented in chapter 7. Below, in section 3.2. of this introduction, the specificities of language related ERPs in children are discussed.

3.2. Language related ERPs in children

In this section, I will summarize the findings regarding language-related ERP components in TD children during their first language acquisition. In chapter 7, the ERP analysis of the processing of prepositions in lexical and functional use by TD children will be presented.

When it comes to collecting EEG data of children, researchers face certain limitations that make the experimental procedure much more challenging than in adults. These challenges include shorter attention span, frequent tiredness, and – especially in young children – limited verbal and motor skills. Despite the restrictions however, one important benefit of the ERP method is that no overt responses are necessary, since EEG directly measures brain activity evoked by specific stimuli. The fact that ERP components directly indicate brain processes means that no explicit task is required and that the brain processes related to certain stimuli may be captured without a behavioral response (Männel, 2009).

The ERP methodology has been successfully employed in language research of TD children in multiple studies (e.g., Silva-Pereyra et al., 2005a; Friedrich and Friederici, 2005b; Holcomb et al., 1992; Atchley et al., 2006; Hahne et al., 2004). In a typical experiment, the ERP processing elicited in children is compared to that of healthy adults, as they represent a baseline against which to assess results from children[6] (Kutas, Van Petten & Kluender, 2006). As a general pattern, ERP components in childhood are initially larger and more broadly distributed both spatially and temporally, whereas the specialized ERP profiles of adults have usually developed by puberty (Holcomb et al., 1992; Hahne et al., 2004).

The lexical-semantic N400 component has been shown to emerge at around 12–14 months and has reliably been found in response to lexical-semantic violation processing in children (e.g., Juottonen et al., 1996; Holcomb et al., 1992; Hahne et al., 2004). The available studies show that its duration decreases with age, as observed in children between 19 months and 2 years (Friedrich and Friederici, 2005) and between 5 and 15 years (Holcomb et al., 1992). N400 amplitude decreases linearly between 5 and 15 years (Holcomb et al., 1992), and its distribution is wider in younger children than in older children or adults (Friedrich and Friederici, 2005, Atchley et al., 2006, Holcomb et al., 1992).

As discussed in more detail in the previous section, ERP studies of morpho-syntactic processing in adults have shown that two ERP components, namely, a late centro-parietal positivity (P600) and a left anterior negativity (LAN), or an early LAN (ELAN) can serve as markers for syntactic processes (Hahne et al., 2004; Friederici, 2006). There are only a few ERP studies of morpho-syntactic processing in children. From these studies it appears that there is a tendency for the P600 component to have a larger amplitude and longer latency compared to that observed in adults (e.g., Friederici and Hahne, 2001; Atchley et al., 2006). As for (E)LAN, it has not been stably

6 The same comparison is applied in ERP studies of infants, older adults as well as individuals with neurological or psychiatric disorders.

detected in studies with children (Friederici, 2006).

Holcomb, Coffey, and Neville (1992) examined developmental changes of the N400 in 130 participants between 5 and 26 years of age. Participants listened to sentences ending either with a highly expected (best completion) or with a semantically inappropriate (anomalous completion) word. In comparison to adults, children produced larger N400s to anomalous words than to appropriate words. The N400 displayed decreased in latency and amplitude with age. According to Holcomb and colleagues, these changes in the morphology of the N400 occurred linearly from 5 until 15 to16 years of age and then stabilized.

Hahne et al. (2004) tested children in age groups of 6, 7, 8, 10 and 13 years who listened to passive sentences that were correct, semantically incorrect, or syntactically incorrect. Children's data in each condition were compared to those of adults. For semantic violations both adults and children demonstrated an N400, but, similarly to the Holcomb et al. (1992) study, the latency decreased with age. At the age of 10 and 13 the timing of the N400 was similar to adults but 7- and 8-year-old children showed a delayed N400. These findings are in general agreement with the Holcomb et al. (1992) study of processing of semantic anomalies in sentence comprehension during development, where the authors observed a decrease in the N400 component's latency as a function of age. However, in contrast to Hahne et al. (2004), Holcomb et al. (1992) also reported a decreased N400 amplitude, which they interpret as evidence of a decrease in the use of contextual information. Hahne et al. suggest that this difference in the results is due to the fact that the sentences used in their study were very short, consisting of one content word and two functional words only, and hence no context effects similar to Holcomb et al. were found.

In the same study (Hahne et al, 2004), adults showed an early left anterior negativity (ELAN), which reflects initial local phrase-structure building processes, and a P600 for syntactic violations. An ELAN and P600 were also present in children between 7 and 13 years, again with latency decreasing with age. Six-year-olds, however, did not display an ELAN effect, but only a late and reduced-amplitude P600 for the syntactic violation. Based on their findings, the authors concluded that semantic processing during auditory sentence comprehension does not change dramatically between early childhood and adulthood. Syntactic processing however, seems to differ between early and late childhood.

Like Hahne et al. (2004), Atchley et al. (2006) studied semantic (N400) and syntactic processing (P600) in children between the ages of 8 and 13 years. The children listened to sentences that were correct, syntactically anomalous, or semantically anomalous. Both adult participants and children in this study showed an N400 in response to semantic anomalies and a P600 to syntactic anomalies. The children's N400, but not their P600, differed from that of adults' in scalp location, amplitude, and latency. In the Atchley et al. study, the differences between adult and child P600s seem to be much less pronounced than in the studies presented above. However, a closer look at their results shows that this is not true for all types of syntactic anomalies. Atchley et al. used two types of syntactic anomalies in their study. The syntactic anomaly was either a verb drop violation or an agreement violation. For the P600 elicited by verb drop violations there were no differences in component amplitude, latency or scalp location observed between adults and children. However, for the agreement violation condition children showed longer component duration in comparison to adults. According to Achley et al., these findings evidence that a P600 is present in children's processing and, although it is similar to that of adults to a certain degree, it is not identical.

Clahsen, Lück and Hahne (2007) examined the processing of inflected word forms in children from 6 to 12 years old and adults. Participants listened to sentences containing correct or incorrect German noun plural forms in sentences. In older children (>8 years) as well as in adults, over-regularized plural forms elicited brain responses that are characteristic of morpho-syntactic violations, i.e., a P600. However, no P600 was observed in younger children (aged 6 to 7 years). Instead, a broadly distributed N400-like negativity was elicited.

In conclusion, the past literature demonstrates that a semantic N400 and a morpho-syntactic P600 are present in the EEG of children to an extant similar to, but not identical with those of adults. The ERPs elicited by processing of syntactic and semantic anomalies appears to change in latency and duration with time, but not in its basic morphology from childhood to adulthood.

As regards the ERP processing of prepositions by TD children addressed in this thesis, what these past studies suggest is that one could expect an N400 in association to the violated/dispreferred prepositions in lexical use, whereas for violations of prepositions in functional use a P600 effect could be expected. However, in comparison to the ERPs elicited in adults, in children both processing effects, an N400 and a P600 could be delayed and/or bigger in amplitude. The effects can be also more widespread in terms of topography in children. However, the global characteristics of these components should be similar between adults and children.

Chapter 4.

Methodology

This chapter describes the methods and data analyses employed to answer the research questions raised in this dissertation. In Chapter 2, we saw that the issue of the syntactic categorization of prepositions is not clear in theoretical research and I discussed the necessity for experimental research of prepositions in lexical and functional use to elucidate this issue. Furthermore, Chapter 2 describes the available literature on the acquisition of prepositions in TD children, which does not give a clear picture as to how these prepositions in different usage are acquired by children. In the same chapter, the significance of studying the acquisition of prepositions in children with CIs was also outlined, as prepositions are potentially problematic for these children in particular, chiefly because of low salience of prepositions. In Chapter 3, I reviewed the ERP findings associated with lexical-semantic and morpho-syntactic violation processing. Distinct ERP components – an N400 for lexical-semantic and a P600 for morpho-syntactic violations – have been reported in literature, which will serve as the basis for exploring the processing of prepositions in lexical and functional usage.

- How are prepositions processed in the human brain? That is, can we find language processing evidence to resolve the problem of the syntactic categorization of prepositions into lexical/functional categories?
- How are prepositions processed in the developing brain?
- Is there a difference in the comprehension and/or production of prepositions between lexical (meaningful) vs. functional (virtually meaningless) usage?
- How are the prepositions in lexical and functional usage acquired by children with profound hearing impairment wearing CIs? Does the fact that prepositions are typically not perceptual salient affect the acquisition of prepositions?

To address these research questions, four studies were conducted, namely, (1) an ERP study of the processing of prepositions in lexical and functional use by adults in Chapter 5, (2) a behavioral study of comprehension and production of prepositions in lexical and functional use by TD children in Chapter 6, (3) an ERP study of the processing of prepositions in lexical and functional use by TD children in Chapter 7, and (4) a behavioral study of comprehension and production of prepositions in lexical and functional use by children with CIs in Chapter 8. The behavioral method involved testing both comprehension and production of prepositions. The stimuli of the comprehension experiment were employed in all four studies (for details see section 4.1). The stimuli of the production experiment were used in both behavioral studies with TD children and children with CIs (see section 4.2). The ERP methodology was applied in the studies with adults and children on the online processing of prepositions (see section 4.3).

More detailed information on the methodology for specific studies is presented in the individual chapters dedicated to each study.

4.1. Stimuli for the comprehension experiment

To examine the comprehension of prepositions, *a sentence acceptability judgement task* was used. Experimental stimuli as well as control sentences were German sentences presented auditorily. Each experimental sentence contained one of twelve monosyllabic prepositions (*auf* 'on', *nach* 'after', *von* 'from', *mit* 'with', *an* 'on', *zu* 'to', *für* 'for', *um* 'at' or 'around', *in* 'in', *aus* 'from', *vor* 'for', *bei* 'at') in either lexical or subcategorized roles (the repetition count of each preposition per sentence type (SubP and LexP) and per condition is given in Table A-1 in Appendix A). To balance the frequency of the prepositions used in the experiment, the twelve most frequently occurring prepositions were selected from the Child Language Data Exchange System (CHILDES) database (MacWhinney, 2000). After selecting the 12 most frequent prepositions from the CHILDES database, I created the experimental stimuli so that for sentences with lexical prepositions the preposition had clear semantic content, e.g., "The man is carrying a package *in* a bag", where *in* has a clear content referencing to a location, whereas in sentences with subcategorized prepositions the preposition had virtually no meaning, e.g., "Everyone picked *on* the new student" (Tseng, 2000) where *on* has no content and is arbitrarily selected by the verb.

For the *sentence acceptability judgement task*, congruent and incongruent sentences were constructed as minimal pairs where only the critical preposition was manipulated (see Table 4.1 below).

Table 4.1. Congruent and incongruent example sentences for each of the preposition types (lexical and subcategorized). Critical words for the ERP analyses are underlined.

	Lexical	Subcategorized
Congruent	Der Bauer schiebt die Kuh *in* einen Stall. "The farmer shoves the cow into the stable." Der Bär klaut den Honig *aus* einem *Nest*. "The bear steals the honey from a nest."	Der Uhu sucht *nach* einer Maus. "The owl looks for a mouse." Das Mädchen sorgt *für* eine *Puppe*. "The girl takes care of a doll."
Incongruent	*Der Bauer schiebt die Kuh *für* einen *Stall*. "The farmer shoves the cow for the stable." *Der Bär klaut den Honig *zu* einem *Nest*. "The bear steals the honey to a nest."	*Der Uhu sucht *von* einer *Maus*. "The owl searches from a mouse." *Das Mädchen sorgt *in* eine *Puppe*. "The girl takes care in a doll."

There were 41 minimal pair sentences for lexical and 41 minimal pair sentences for subcategorized prepositions (see Appendix A for the complete list of sentences used in the experiments). Sentences with lexical prepositions will be referred to as LexP sentences and sentences with subcategorized prepositions as SubP sentences. Most prepositions were used in both conditions (congruent and incongruent) each for LexP and SubP sentences (Table A-1 in Appendix A). Only *für* was not used in any congruent LexP sentences and only *um* was not used in any incongruent LexP sentences. In the congruent SubP sentences, it was not always possible to use all twelve prepositions because the choice of prepositions by the verb is fixed and hence limited. As a result, *um, aus, bei,* and *in* were not used in this condition. However, all 12 prepositions were included in the incongruent condition of the SubP sentences. In LexP sentences, the PP was an adjunct after the argument DP. All verbs were mono-syllabic in their conjugated forms. According to the Leipzig Corpora Collection (Biemann et al. 2007) the verbs in LexP sentences ranged from frequency class[7] 7 to 17 (median 10; mean 10.8 SD 3.1) and the verbs in SubP sentences ranged from class 7 to 13 (median 9; mean 9.5 SD 1.6). As for the 12 prepositions, their frequency class, based on word form (i.e., including all types of usage), ranged from 1 to 3.

The experiment also included 82 control sentences of similar length and lexical material to the experimental sentences, but without prepositions. Half of the control sentences were semantically incongruent, that is, the sentence-final nouns were incongruent completion of the preceding context in half of the sentences. The nouns used in the control sentences (both in congruent and incongruent sentences) were limited to the ones which occurred in the most frequent 25th percentile of childLex: A lexical database for German read by children (Schroeder et al., 2014) (the complete list of the control sentences is given in Appendix A). This resulted in a total of 246 sentences. Average duration and duration ranges of the LexP, SubP and control sentences in each condition (congruent and incongruent) are given in Table 4.2.

To test the validity of congruent and incongruent experimental and control sentences, two pretests were run on separate groups of participants. First, sentence acceptability was examined for all sentence types in all conditions (including the controls). Twenty-eight participants[8], who were monolingual German speakers (age range 18 -30 years) rated the sentences on a 6-point-scale (6 for non-acceptable, 1 for highly acceptable). Initially, there were 110 LexP sentence (i.e., 55 pairs), 104 SubP sentences (i.e., 52 pairs) and 100 fillers (i.e., 50 pairs) in the pretest. Sentence pairs

7 In this corpus the frequency class is calculated based on a logarithmic scale relative to the most frequent word in the corpus. For example, one of the most frequent German words *und* (and) has the frequency class of 0 while the least frequent words end up in frequency classes of 21 to 24.

8 None of the participants from the pretests took part in the ERP experiment.

were rejected if the rating for (a) the congruent sentence did not differ significantly from that for incongruent sentences overall, (b) the incongruent sentence did differ significantly from that for incongruent sentences overall, or (c) the congruent sentence and the incongruent sentence in the particular pair did not differ (or any combination of a, b, and c) as tested by Wilcoxon rank-sum-test. The average acceptability for the congruent and incongruent LexP sentences included in the experiment was 2.0 (SD 0.7) and 5.1 (SD 0.7), respectively and 1.9 (SD 0.7) and 5.0 (SD 0.7), respectively, for the congruent and incongruent SubP sentences. As a result of the pretesting, 28 LexP, 22 SubP and 18 control sentences were rejected.

Table 4.2. Average duration and duration ranges in milliseconds for LexP, SubP and control sentences per condition.

Sentence type and Condition	Average duration (SD) (in ms)	Duration range (in ms)
LexP congruent	2955 (SD 182)	2498-3358
LexP incongruent	2878 (SD 193)	2534-3310
SubP congruent	2354 (SD 128)	2061-2656
SubP incongruent	2400 (SD 154)	2090-2758
Control congruent	2765 (SD 184)	2378-3192
Control incongruent	2690 (SD 220)	2354-3400

After this, to assess whether all prepositions allow for a sensible sentence completion in the experimental sentences (no control sentences were tested here), a sentence completion task was employed. The task was conducted with congruent and incongruent LexP sentences and with incongruent SubP sentences. A separate group of 25 mono-lingual German participants did the completion task for LexP sentences (both conditions). Another group of 7 mono-lingual German speakers performed the completion task for incongruent SubP sentences. The congruent SubP sentences were not included in this pretest because in these sentences the prepositions are selected by the verbs (they represent one lexical unit) and hence it makes no sense to question whether the preposition allows for a sensible sentence completion, they always do. Participants were given the experimental sentences up until the preposition (e.g., *Der Mann trägt das Paket in … …*) and were asked to complete the sentence using only two words. On the pretest, participants were asked to use only two words to complete the sentences because this was the structure used during the experiment. For incongruent SubPs, the aim was to check whether the prepositions indeed did not fit the verb and hence were dispreferred continuations of the sentence. When it comes to LexP sentences, prepositions are less dependent on the preceding verb and thus I wanted to examine in how far prepositions allowed for appropriate sentence completions.

Furthermore, to control the level of difficulty of integrating prepositions into the context for congruent and incongruent LexP sentences, in addition to sentence completion, participants were asked to rate the difficulty of this completion on a 6-point Likert scale (6 for very difficult, 1 for very easy). Average completion ratings were 1.8 (SD 0.5) for congruent LexP and 2.5 (SD 0.9) for incongruent LexP sentences, which indicates that the prepositions in the incongruent condition were indeed slightly dispreferred.

Participants were unable to complete most of the incongruent SubP sentences with only two words, which shows that after the incongruent preposition the sentence becomes difficult to complete, and this confirms the incongruency of these sentences at the point of the preposition. As for congruent and incongruent LexP sentences, participants were able to complete almost all sentences correctly. This confirms that incongruent LexP sentences were not yet incongruent at the point of the preposition.
Because this sentence material was also used for the studies with children, I wanted to make sure that children should have typically acquired the verbs used. For this reason, the verbs used in LexP sentences were controlled for age of acquisition (AoA) which ranged from 2;6 to 4;5 years as stated in the study by De Bleser and Kauschke (2003). Since the verbs in SubP sentences had to be chosen for specific prepositions (12 mono-syllabic), I was limited in choice and hence was not able to use AoA for these verbs. Instead, highly frequent verbs were used assuming that because of their frequency children in this study should have acquired them. As noted above, the frequency was determined according to the Leipzig Corpora Collection.

Participants in the comprehension experiment were instructed to listen to the sentences and press a dedicated button when they encountered a sentence which did not make sense. For a detailed description of the procedure of the comprehension experiment see Chapter 5 (adults) and Chapter 6 (children).

4.2. Stimuli and procedure for the production experiment

To examine the production of prepositions in children, I employed two types of contrastive elicitation tasks each serving a particular aim. The aim of the first part of the experiment was to elicit the same prepositions as prompted by the experimenter and thus test children's knowledge of specific lexical and subcategorized prepositions (*contrastive elicitation task I*). In the second part, I tested children's ability to manipulate the prepositions prompted by the experimenter using a completely different preposition which would correctly describe the picture (*contrastive elicitation task II*). In addition to the mono-syllabic prepositions used in the comprehension experiment, the production experiment also used bi-syllabic prepositions. The structure of the sentences was the same as in the comprehension study.

The *contrastive elicitation task I* consisted of sentence-picture pairs, half of which were used as prompts from the experimenter and the other half as children's expected target responses. The prepositions were the same in the prompt and target response sentences. In fact, only the last DP differed between prompts and target responses. This way it was possible to minimize the confounding effects of general lexical knowledge in children. In total, 12 prompts were used to elicit 12 lexical prepositions (panels A and B in Figure 4.1) and 12 prompts to elicit subcategorized prepositions (panels C and D in Figure 4.1).

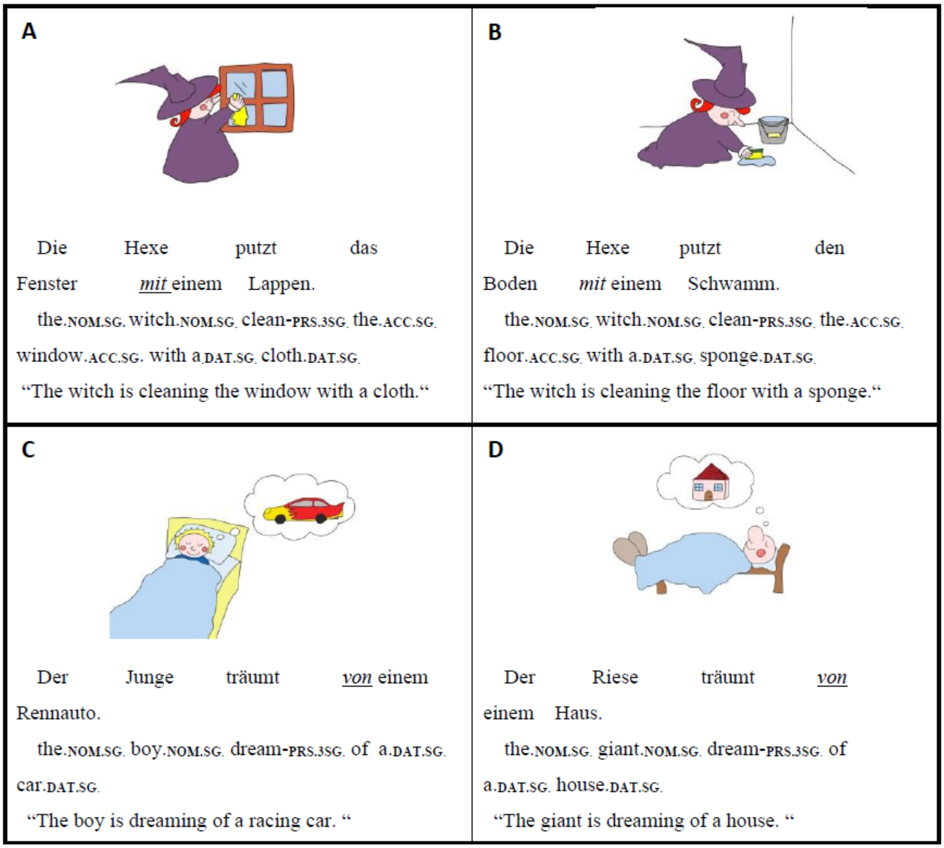
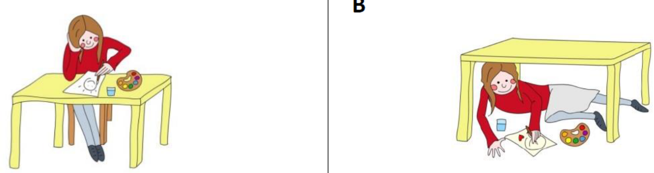


Figure 4.1. Example picture-sentence pairs used in the contrastive elicitation task I. LexP sentences are shown above in panels A and B. Panel A is a picture-sentence pair prompted by the experimenter

and panel B is a possible correct response. SubP sentences are shown below in panels C and D. C shows a picture-sentence pair prompted by the experimenter and D is a possible correct response.

During the experiment, participants first saw a picture on a computer screen (left-side pictures on Figures 4.1), which was described by the experimenter who was a native speaker of German and presented sentences orally in a neutral intonation and at a normal speaking rate: „Die Hexe putzt das Fenster mit einem Lappen." (The witch is cleaning the window with a cloth). Next, a second picture appeared on the computer screen (right-side pictures on Figures 4.1) and the children were instructed that it was their turn to describe the second picture similarly to how the experimenter described the previous picture. Subsequently participants would produce a target sentence, for example: „Die Hexe putzt den Boden mit einem Schwamm." (The witch is cleaning the floor with a sponge).

In the *contrastive elicitation task II*, the target response pictures were designed to elicit a different (or contrasting) preposition from the one used in the experimenter's prompt. Only prepositions differed between the prompt and expected response sentences, the rest of the lexical material was the same (Figure 4.2). In this part, only lexical prepositions were used because usually a verb subcategorizes only for one specific preposition. Hence, it is almost impossible to create minimal pairs with subcategorized prepositions.



A

Das Mädchen malt das Bild <u>an</u> einem Tisch.
the.NOM.SG. girl.NOM.SG. draw-PRS.3SG. the.ACC.SG. picture.ACC.SG. on a.DAT.SG. table.DAT.SG.
"The girl draws the picture at a table."

B

Das Mädchen malt das Bild <u>unter</u> einem Tisch.
the.NOM.SG. girl.NOM.SG. draw-PRS.3SG. the.ACC.SG. picture.ACC.SG. under a.DAT.SG. table.DAT.SG.
"The girl draws the picture under a table.

Figure 4.2. Example picture-sentence pairs used on contrastive elicitation task II. Panel A is a sentence with a preposition prompted by the experimenter; panel B is an expected possible response with a different preposition from the one used by the experimenter.

Similarly to the procedure on *contrastive elicitation task I*, on the *task II* children were instructed to first listen to the experimenters' description of the picture and then to describe a similar picture imitating the experimenter. Specifically, participants first saw a picture on a computer screen (left-side picture on Figure 4.2), which was described by the experimenter in a neutral intonation and at a normal speaking rate: ,,Das Mädchen malt das Bild an einem Tisch." (The girl draws the picture at a table). Next, a second picture appeared on the computer screen (right-side picture on Figure 4.2) and the children had to describe the picture similarly to the experimenter's description. Subsequently, participants would produce a target sentence, for example: ,,Das Mädchen malt das Bild unter einem Tisch" (The girl draws the picture under a table).

Each response was scored as either a target or a non-target response. Responses with incorrect prepositions (i.e., prepositions which did not correctly describe the situation on the picture) and omissions of prepositions (the pictures were designed so that the use of a preposition was obligatory) were categorized as non-target responses. The use of valid alternatives to the target prepositions, i.e., prepositions which were not in the initial target responses but still correctly described the picture were counted as target responses. Children with CIs used valid alternatives 12% of all responses, while the control group used valid alternatives 8% of the times. Errors or (incorrect) substitutions of other word categories (determiners, nouns) were not taken into account as long as the sentence produced was comprehensible and described the situation depicted in the picture.

4.3. Stimuli for the ERP experiment

The sentence stimuli (Table 4.1 repeated below) used in the comprehension experiment were also used for collecting the ERP data.

Table 4.1. Congruent and incongruent example sentences for each of the preposition types (lexical and subcategorized). Critical words for the ERP analyses are underlined.

	Lexical	Subcategorized
Congruent	Der Bauer schiebt die Kuh *in* einen Stall.	Der Uhu sucht *nach* einer Maus.
	"The farmer shoves the cow into the stable."	"The owl looks for a mouse."
	Der Bär klaut den Honig *aus* einem *Nest*.	Das Mädchen sorgt *für* eine *Puppe*.
	"The bear steals the honey from a nest."	"The girl takes care of a doll."
Incongruent	*Der Bauer schiebt die Kuh *für* einen *Stall*.	*Der Uhu sucht *von* einer *Maus*.
	"The farmer shoves the cow for the stable."	"The owl searches from a mouse."
	*Der Bär klaut den Honig *zu* einem *Nest*.	*Das Mädchen sorgt *in* eine *Puppe*.
	"The bear steals the honey to a nest."	"The girl takes care in a doll."

For the ERP studies, two critical words in each experimental sentence were triggered. These words were the preposition, which was manipulated to create minimal pairs of congruent and incongruent sentences, and the final noun (which is also the last word; see underlined words in Table 4.1). This had the following motivation: while lexical prepositions are fairly easily exchangeable in almost any sentence context, subcategorized prepositions are much more fixed to the preceding verb (in fact, they are specifically selected by the verb), which makes them virtually impossible to exchange. Consequently, for lexical prepositions it is difficult to create an incongruent condition in which the incongruity in the sentence is clearly detectable at the preposition. Moderately dispreferred combinations of a verb and a lexical preposition are possible as pretested by German native speakers (see section 4.4). Therefore, one can argue that in the context of an incongruent preposition, the processing difficulty would be more readily detectable on the noun rather than at the preposition itself. In contrast, subcategorized prepositions in the incongruent condition are in a strongly dispreferred combination with the preceding verb, which should inflict processing costs already at that point. This occurrence of the processing effect on the subcategorized preposition, however, does not exclude an additional effect on the noun in SubP sentences in the context of an incongruent preposition. In sum, prepositions both in LexP and SubP sentences were manipulated, but this manipulation of prepositions created dispreferred combinations of a verb and a preposition rather than outright violations (this dispreference was much stronger in case of subcategorized prepositions because of them being subcategorized by the preceding verbs). The nouns in all PPs, however, resulted in clear violations as a result of the manipulation of prepositions.

Participants were instructed to identify sentences which sounded senseless to them by pressing a dedicated button. The details of the procedure in the ERP experiment are given in Chapters 5 and 7 for adult and child participants, respectively.

4.4. EEG Recording and data analysis

As noted in the beginning of this chapter, ERP methodology was used in the study with adult participants reported in Chapter 5 and in the study with children reported in Chapter 7.

EEG was recorded from 32 Ag/AgCl electrodes secured to an elastic cap (EasyCap, Herrsching, Germany) using a BRAIN AMP Series amplifier system and Brain Vision Recorder (both from Brain Products GmbH, München, Germany). The specific electrode locations were Fp1/2, F7/8, F3/4, Fz, Ft9/10, Fc1/2, Fc5/6, T7/8, C3/4, Cz, Cp5/6, Cp1/2, Tp9/10, P7/8, P3/4, Pz, O1/2, and Oz. AFz served as ground electrode. Recordings were referenced to the nose-tip. Fp1 and Fp2 were used to record the electro-oculogram (EOG) in order to control for vertical and (to a lesser extent) horizontal eye movements. The data were recorded at a 250 Hz sampling rate and analog filtered between 0.1 and 100 Hz. Electrode impedances were maintained mostly at 10 kOhm, with all at least below 20 kOhm (cf. Viola et al., 2012; Finke, et al., 2016) prior to data acquisition. Although traditionally electrode impedance levels in neurolinguistics studies have been kept below 5kOhm, electrical engineering research shows that high impedance levels do not deteriorate the quality of the recorded signal (for review see Ferree et al., 2001). In fact, keeping a higher impedance threshold has a number of advantages such as less preparation time and avoidance of hygienic issues.

EEG data were analyzed with MATLAB 8.1.0.604 (R2013a; Mathworks, Natick, MA) and EEGLAB (version 13.4.4b, Delorme and Makeig, 2004). Continuous EEG data were high-pass filtered at 1 Hz and then low-pass filtered at 40 Hz (sinc FIR filters windowed with a Hanning window, cutoff frequency -6 dB) for artifact attenuation with independent component analysis (ICA). Dummy regular epochs of 1000 ms were generated. The data were then pruned of unique, non-stereotype artifacts, i.e., epochs displaying three or more standard deviations from the mean signal were rejected. Subsequently, an extended infomax ICA (Makeig, Debener, Onton, & Delorme, 2004) was applied and the unmixing ICA weights were copied and saved to the raw data (for example, Finke et al., 2016; Fjaellingsdal et al., 2016).

For ERP analysis, the raw data with ICA weights was high-pass filtered at 0.1 Hz and low-pass filtered at 30 Hz (sinc FIR filters windowed with a Hanning window, cutoff frequency -6 dB). Artifactual ICA components were identified by visual inspection and removed. The data were epoched -200 – 2200 ms relative to critical preposition onset, i.e., including the whole PP. The epochs were baseline corrected -200 – 0 ms relative to preposition onset. Since this baseline correction applies to the whole PP epoch, it provides a similar, non-contaminated baseline for both critical words (the preposition and the final noun). Epochs with non-stereotypical artifacts displaying three or more standard deviations from the mean signal were rejected.

Chapter 5.

Prepositions as a hybrid between lexical and functional category: Evidence from an ERP study on German sentence processing [9]

9 Parts of this chapter are based on: Chanturidze, M., Carroll, R., & Ruigendijk, E. (2019). Prepositions as a hybrid between lexical and functional category: Evidence from an ERP study on German sentence processing. *Journal of Neurolinguistics*, 52, 100857.

Abstract

In syntactic theories of word categorization the status of prepositions as belonging to either a lexical (e.g., nouns, verbs) or a functional category (e.g., determiners, complementizers) is under debate. It has also been suggested that prepositions are a hybrid between the two categories depending on their usage. The classification question was empirically investigated in an ERP study with twelve mono-syllabic German prepositions in lexical (e.g., locative prepositions as in *on the table*) and subcategorized (e.g., selected by the verb as in *waiting for*) use. Thirty adult participants listened to sentences containing prepositions either in lexical or subcategorized use. Violations to lexical prepositions elicited an N400 – a component typically associated with lexical-semantic processing. Violations to subcategorized prepositions elicited a P600 – a component typically associated with structural/syntactic processing. In addition to lexical and subcategorized prepositions, the processing of sentence-final nouns following each type of preposition was measured. In both cases P600 effects were elicited. In addition to the positive effect, nouns in the context of incongruent lexical prepositions elicited an N400 effect. These qualitatively different processing results for lexical and subcategorized prepositions (and for nouns in the context of prepositions) suggest that depending on their use prepositions are processed like lexical or like functional words. By providing empirical evidence, I can conclude that in terms of syntactic categorization, prepositions should be classified as a hybrid between a lexical and functional category.

5.1. Brief introduction and research questions

In the present chapter I will describe an ERP study designed to examine whether prepositions are lexical, functional or a hybrid between the two categories. If prepositions as a class of words are more like lexical categories their violation should elicit an N400, a component related to lexical-semantic processing. If on the other hand, prepositions are a functional category, their violation should elicit a P600, a component associated with morpho-syntactic reanalysis. If, however, prepositions are a hybrid between the two categories their violations should elicited an N400 in more lexical usage (lexical prepositions, Table 4.1 reproduced below) and a P600 in more functional usage (subcategorized prepositions, Table 4.1).

5

Table 4.1. Congruent and incongruent example sentences for each of the preposition types (lexical and subcategorized). Critical words for the ERP analyses are underlined.

	Lexical	Subcategorized
Congruent	Der Bauer schiebt die Kuh *in* einen Stall. “The farmer shoves the cow into the stable.“ Der Bär klaut den Honig *aus* einem *Nest*. “The bear steals the honey from a nest.”	Der Uhu sucht *nach* einer Maus. “The owl looks for a mouse.“ Das Mädchen sorgt *für* eine *Puppe*. “The girl takes care of a doll.”
Incongruent	*Der Bauer schiebt die Kuh *für* einen *Stall*. “The farmer shoves the cow for the stable.“ *Der Bär klaut den Honig *zu* einem *Nest*. “The bear steals the honey to a nest.”	*Der Uhu sucht *von* einer *Maus*. “The owl searches from a mouse.“ *Das Mädchen sorgt *in* eine *Puppe*. “The girl takes care in a doll.”

Judging from the linguistic properties of lexical and subcategorized prepositions as listed in Table 2.1 (reproduced below from Chapter 2), I hypothesized that lexical prepositions would be processed more like lexical categories, whereas subcategorized prepositions, since they share more properties with functional categories, would be processed more like functional elements.

Table 2.1. Characteristic properties of lexical and subcategorized prepositions.

Properties	Lexical	Subcategorized
Relatively specific semantic meaning	Yes	No (non-conceptual meaning)
Dependence on Verb	No	Yes
Class membership	Closed	Closed
Thematic role assignment	Yes	Not clear/controversial
Case marking	Yes	Yes

More specifically, an N400 in sentences with incongruent lexical prepositions and a P600 in sentences with incongruent subcategorized prepositions was expected.

Although anterior negativities have been observed for the processing of syntactic violations, I did not expect to find this component as a result of the experiment due to the specific design of the stimuli (in this case sentences with subcategorized prepositions). The incongruent sentences with subcategorized prepositions were not created as outright syntactic violations, but rather as dispreferred structures involving these prepositions. That is, at the preposition the sentence is not ungrammatical. Thus, since it has been argued in the literature (Friederici, 2001; Swaab et al. 2012) that a P600 is correlated with both outright violations *and* dispreferred structures, and an (E)LAN has been elicited only for actual violations, no E(LAN) in sentences with manipulated subcategorized prepositions was expected.

5.2. Method

The sentence stimuli used in this ERP experiment were the same as in the comprehension experiments described in detail in section 4.1, Chapter 4. For the design of the ERP experiment employed in this study, please see sections 4.3, which gives information about the critical words which were triggered for the analysis and the motivation behind the choice of those critical words. Section 4.4 describes the EEG recording and analysis applied to the data for the current study.

5.2.1. Participants

Thirty adult German-native speakers (16 female) participated in the study. The mean age of participants was 24 years (range: 18 – 33; SD: 3.08 years). All were right-handed according to a German adaptation of the Edinburgh Handedness Inventory (Oldfield, 1971). Participants gave written informed consent prior to testing and received payment for participation. The study was approved by the Ethics Committee of the University of Oldenburg and conducted in accordance with the declaration of Helsinki. According to their self-report on the questionnaire, all of the subjects were hearing normally, none had any neurological impairment, had experienced any neurological trauma, or used antipsychotic medications.

5.2.2. Procedure

After the EEG cap was mounted, the participants were seated in a sound attenuated booth in front of a computer screen. Sentences were presented auditorily via two

Genelec loudspeakers at 65 dBA RMS. Participants were asked to avoid eye-blinks and other movements during sentence presentation. Each participant listened to all sentences presented in 8 experimental blocks of 3 minutes each. After 4 blocks they were given an opportunity for a break of maximally 10 minutes, while after the other blocks a brief break was allowed to let them rest their eyes. To ensure concentration, participants were instructed to perform a *sentence acceptability judgement task*: they had to identify whether each sentence made sense by pressing a dedicated button on a joystick (red for senseless and green for sensible sentences). Each trial began with the presentation of a fixation cross for 700 ms followed by presentation of the sentence while the fixation cross remained in the center of the screen. After sentence offset, the cross was subsequently replaced by a question mark indicating a request for judgement via button press. A practice session of nine trials familiarized participants with the task. Experimental sessions, including electrode application, lasted 1.5–2 hours. The order of the sentences was pseudo-randomized in two different lists to avoid order effects. All stimuli were recorded by one female speaker, while the instructions were given both in written and oral form.

Stimulus presentation was controlled using E-Prime 2.0 experimental software (PST, Sharpsburg, PA) (www.pstnet.com/products/e-prime/).

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5.3. Statistical analysis

For statistical analysis of each particular critical word (the preposition and the noun), the long PP epochs were re-epoched into shorter epochs of -200 – 1100 ms relative to each preposition and noun. The electrodes were grouped using the factors laterality (left, central or right) and anteriority (anterior or posterior; cf. Ruigendijk et al., 2016), resulting in six regions of interest: left anterior (F3, Fc5, C3, F7), central anterior (Fz, Fc1, Fc2, Cz), right anterior (F4, Fc6, C4, F8), left posterior (Cp5, P3, P7, O1), central posterior (Cp1, Cp2, Pz, Oz) and right posterior (Cp6, P4, P8, O2).

All analyzable trials were included in the ERP analyses (the number of observations for each analysis is given in the respective LMM tables in Appendix B).
The time windows for statistical analyses for the expected N400 and P600 components were determined based on a combination of visual waveform inspection for each critical word and existing literature on auditory ERPs (e.g., Hagoort, 2008). This resulted in the following time windows for the critical words (preposition and final noun, see underlined words in Table 4.1):

LexP sentences:

- Preposition: biphasic negative going waveform with time windows 100 – 250 ms and 300 – 550 ms
- Noun: early time window of 300 – 550 ms (negative going waveform) and late time window of 550 – 1000 ms (positive going waveform)

SubP sentences:

- Preposition: late time window of 550 – 1000 ms (positive)
- Noun: late time window of 550 – 1000 ms (positive)

In addition to the analyses of these time windows for the hypothesized effects, additional analyses were also run for (a) the late time window (550 – 1000 ms), i.e., for a P600 for the lexical preposition and (b) for the early time window (300 – 550 ms), i.e., for an N400 for the subcategorized preposition. Mean amplitudes for these time windows were analyzed statistically. Early time windows were analyzed for an N400 effect while the late time windows were analyzed for a P600 effect/late positive component (LPC). Since the early time window for the noun (i.e., N400) in the sentences with subcategorized prepositions overlapped with the effect from the late time window of the preposition (P600), this time window was not analyzed (it would interact with the late positive effect on the preposition and be impossible to disentangle from that effect).

Statistical analyses were conducted using linear mixed-effects models (LMM) with crossed random effects for participants and items (Baayen et al., 2008). Analyses were carried out using R (R Core Team, 2014) and the lme4 package for linear mixed-effects models (LMMs; Bates et al., 2015). Participants and items were modeled as random effects, whereas factors condition (congruent vs. incongruent), laterality (left, central, right), and anteriority (anterior vs. posterior) were modeled as fixed effects (full factorial model). Separate models were run for each type of preposition (lexical and subcategorized). Both random and fixed effects were the same for all analyses.

In order to compare the processing of prepositions and nouns in LexP and SubP sentences, difference waveforms – computed by subtracting the waveform to a congruent critical word from the waveform to an incongruent critical word – were also analyzed. This analysis was conducted in three time windows to compare effects on lexical and subcategorized prepositions directly, namely, 100 – 250 ms, 300 – 550 ms and 550 – 1000 ms, while for the nouns in each type of sentence only the 550 – 1000 ms time window was tested. The LMM model for the difference waveform analysis included participants as a random effect, whereas factors sentence type (LexP vs. SubP), laterality (left, central, right), and anteriority (anterior vs. posterior) were modeled as fixed effects.

5.4. Results

5.4.1. *Behavioral results*

Participants' overall accuracy on the *sentence acceptability judgement task* was 95% (SD 3.08). Accuracy on sentences with lexical prepositions was 95% (SD 4.07) and on sentences with subcategorized prepositions also 95% (SD 3.25). For the control sentence, the performance was 79% (SD 8.3) accurate.

5.4.2. *ERP results*

Crucial to the hypothesis of the study, the critical words in LexP sentences and SubP sentences elicited qualitatively different ERP components. In incongruent LexP sentences there were condition effects in the time window for N400 for both critical words (lexical preposition & noun) as well as a late positivity following the noun. In addition to the predicted ERP effects, lexical prepositions elicited an N200 preceding the N400 effect. In contrast, critical words in SubP sentences had condition effects only with positive going waveforms in the late time window (i.e., 550 – 1000 ms). As expected, no negative effects were found relative to subcategorized prepositions. The analysis of the 300 – 550 ms time window nevertheless revealed a small positive effect at the preposition (Figure 5.1, Panel B). The results are discussed in more detail in the following sections.

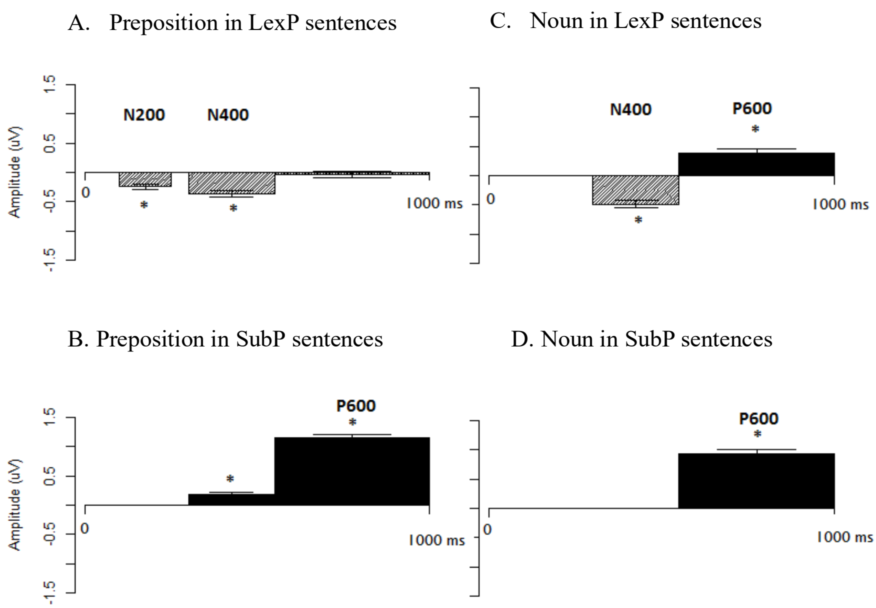

Figure 5.1. Polarity and estimated effect sizes in microvolts for each critical word in early and late

time windows. Panel A shows the three time windows (100 – 250 ms; 300 – 550 ms; 550 – 1000 ms) analyzed following the prepositions in LexP sentences. Panel B shows the time windows (300 – 550 ms & 550 – 1000 ms) analyzed following prepositions in SubP sentences. The time windows analyzed (300 – 550 ms; 550 – 1000 ms) following the nouns in LexP sentences are given in Panel C, while Panel D shows the time window (550 – 1000 ms) analyzed for the nouns in SubP sentences. Solid black bars represent positive effects and shaded bars negative effects.

Sentences with Lexical Prepositions

Grand average ERPs and topoplots for lexical prepositions are given in Figure 5.2.

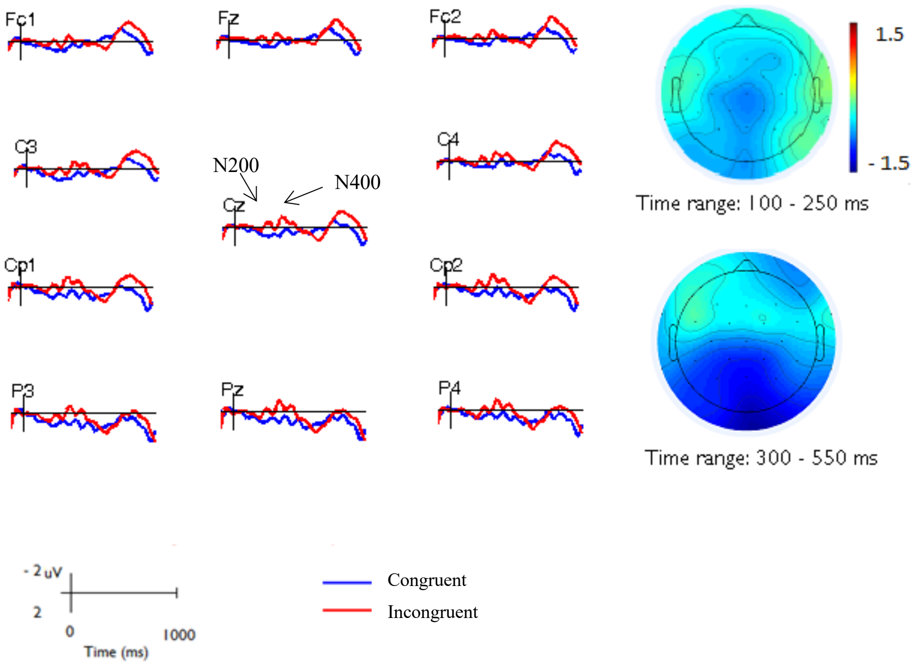

Figure 5.2. The processing of lexical prepositions in LexP sentences. Panel A shows grand average ERPs for congruent (blue line) and incongruent (red line) lexical prepositions. The onset of the preposition is at 0 ms. Panel B gives topographical information for the N200 (time range 100 – 250 ms) and N400 (time range: 300 – 550 ms) effects.

In the earlier negative time window (100 – 250 ms) after the preposition, i.e., for the N200 effect, there was a significant main effect of condition (congruent vs incongruent) (Table 5.1). In this time window, the incongruent condition elicited a negativity relative to the congruent condition. The condition by laterality (left, central, right), condition by anteriority (anterior vs posterior), laterality by anteriority, and condition by anteriority by laterality interactions were not statistically significant (see Appendix B, Table B-2 for the full model summary). Hereafter only significant effects relevant to the research question and hypotheses of the study will be reported, while the full results can be found in Appendix B.

Table 5.1. Brief summary with estimated effect sizes and significance levels of the LMM statistics relative to the lexical preposition in three time windows: 100 – 250 ms, 300 – 550 ms, and 550 – 1000 ms. The full statistical model is given in Appendix B, Tables B-2, B-3 and B-4.

	Time window (component)	Estimate	Std. Error	t value
Condition	100 – 250 ms (N200)	.24	.04	5.67***
	300 – 550 ms (N400)	.37	.04	7.38***
	550 – 1000 ms (P600)	.04	.05	.79
Condition x anteriority	300 – 550 ms (N400)	-.13	.04	-2.83**

Significance codes: *** $p < 0.001$. ** $p < 0.01$. * $p < 0.05$.

In the consecutive time window (300 – 550 ms) after the preposition, in which I expected an N400, the analyses revealed a statistically significant main effect of condition and a significant condition by anteriority interaction, indicating that the effect was more prominent in the posterior region (Table 5.1). In this time window, the incongruent condition showed a negativity relative to the congruent condition and this effect was most prominent over posterior sites. For the late positive time window (550 – 1000 ms) following the lexical preposition neither the main effect of condition nor that of any interaction was significant (Appendix B, Table B-4).

Table 5.2. Brief summary with estimated effect sizes and significance levels of the LMM statistics relative to the nouns in LexP sentences in two time windows: 300 – 550 ms and 550 – 1000 ms. The full statistical model is given in Appendix B, Tables B-5 and B-6.

	Time window (component)	Estimate	Std. Error	t value
Condition	300 – 550 ms (N400)	.48	.06	7.68***
	550 – 1000 ms (P600)	-.38	6.71	-5.74***
Condition x laterality	300 – 550 ms (N400)	.14	.08	-1.48
Condition x anteriority	550 – 1000 ms (P600)	3.13	.06	4.69***

Significance codes: *** $p < 0.001$. ** $p < 0.01$. * $p < 0.05$.

In the early time window (300 – 550 ms) for the N400 effect following the noun, there was a significant main effect of condition, the incongruent condition being more negative, and a marginally significant interaction of condition by laterality, the effect being most prominent at electrodes near the midline (Table 5.2). Furthermore, in the late time window (550 – 1000 ms), i.e., for the P600 effect, a significant main effect of condition was found, with the incongruent condition showing a stronger positivity than the congruent condition. Also, a significant condition by anteriority interaction was found following the noun (Table 5.2), indicating that the condition effect was stronger at posterior electrodes. Grand average ERPs and topoplots for the nouns in LexP sentences are given in Figure 5.3.

A significant main effect of condition was observed after the preposition in the SubP sentences, as well as interactions of condition by laterality and condition by anteriority in the late time window (550 – 1000 ms) tested for a P600 effect (Table 5.3). In this time window, the incongruent condition elicited a stronger positivity relative to the congruent condition for the subcategorized preposition. Examination of the interaction effects shows that the P600 effect was strongest at electrodes over centro-parietal areas.

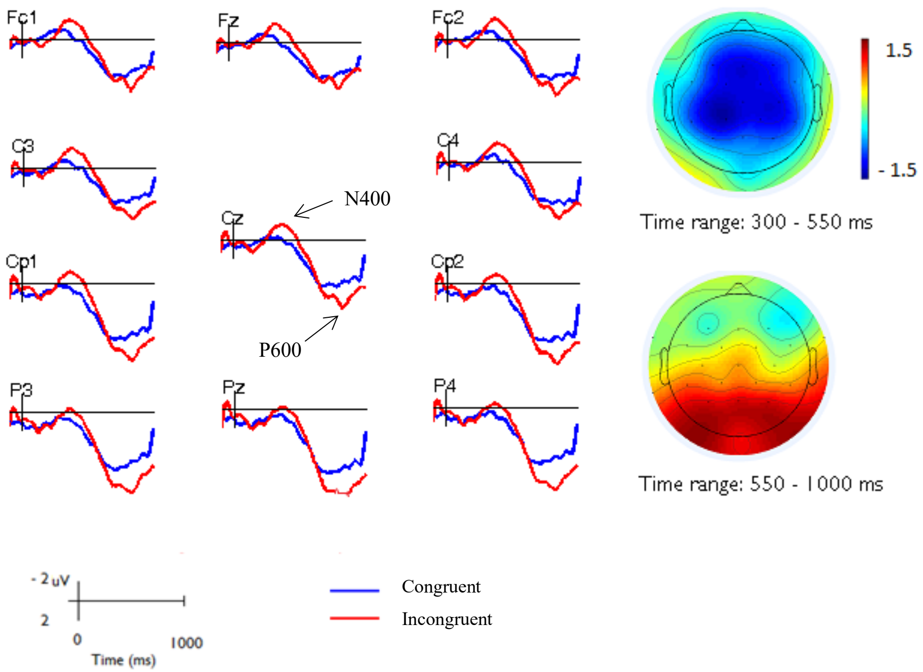

Figure 5.3. Panel A shows grand average ERPs for congruent (blue line) and incongruent (red line) nouns in sentences with lexical prepositions. The onset of the noun is at 0 ms. Panel B gives topographical information for the N400 (time range: 300 – 550 ms) and P600 (time range: 550 –

1000 ms) effects.

Sentences with Subcategorized Prepositions

Figure 5.4 depicts grand average ERPs and topoplots for prepositions in SubP sentences.

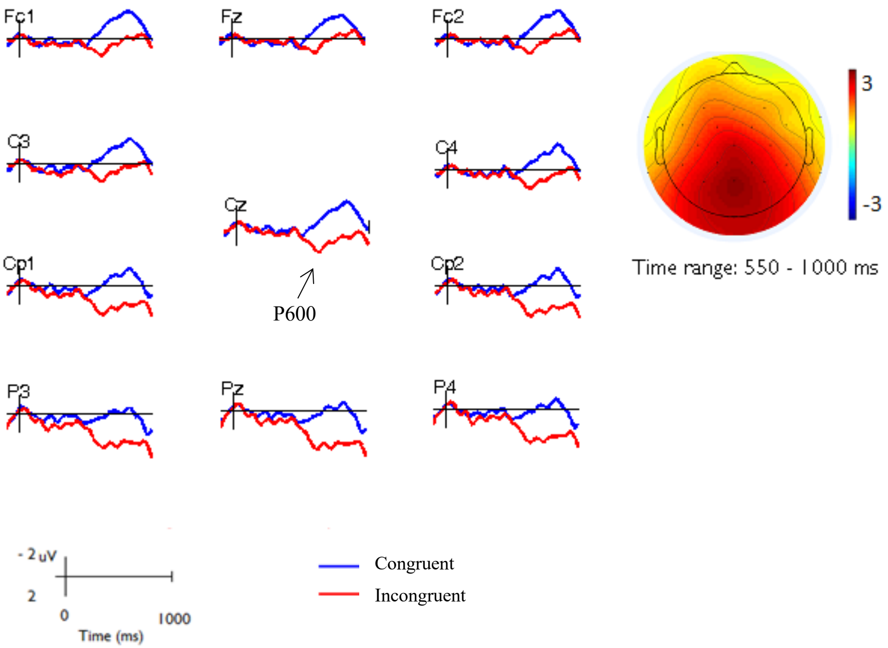

Figure 5.4. The processing of subcategorized prepositions in SubP sentences. Panel A shows grand average ERPs for congruent (blue line) and incongruent (red line) subcategorized prepositions. The onset of the preposition is at 0 ms. Panel B gives topographical information for the P600 (time range: 550 – 1000 ms) effects.

Table 5.3. Brief summary with estimated effect sizes and significance levels of the LMM statistics relative to subcategorized prepositions in the time window: 550 – 1000 ms. The full statistical model is given in the Appendix B, Table B-8.

	Time window (component)	Estimate	Std. Error	t value
Condition	550 – 1000 ms (P600)	-1.15	.05	-20.93***
Condition x laterality	550 – 1000 ms (P600)	-.19	.07	-2.45*
Condition x anteriority	550 – 1000 ms (P600)	.24	.05	4.38***

Significance codes: *** $p < 0.001$. ** $p < 0.01$. * $p < 0.05$.

The early time window was tested for the N400 effect (300 – 550 ms) for subcategorized prepositions as well, to compare with the analyses of the lexical prepositions, but no negative-polarity condition effect or any interaction was found (Appendix B, Table B-7). Instead, I observed a small but statistically significant positive effect, i.e., a condition effect was found with the incongruent condition being slightly more positive than the congruent one. There was a condition by anteriority interaction indicating that this effect was strongest at posterior electrodes.

As for the late time window (550 – 1000 ms) tested for the P600 effect related to the noun in SubP sentences both the main effect of condition and the condition by anteriority interaction were significant (Table 5.4), indicating a P600 effect most prominent over posterior regions (see Figure 5.5 for the grand average ERPs for the nouns in SubP sentences).

Table 5.4. Brief summary with estimated effect sizes and significance levels of the LMM statistics relative to the nouns in SubP sentences in the time window: 550 – 1000 ms. The full statistical model is given in Appendix B, Table B-9.

	Time window (component)	Estimate	Std. Error	t value
Condition	550 – 1000 ms (P600)	-.93	.06	-13.88***
Condition x anteriority	550 – 1000 ms (P600)	-.31	.06	4.74***

Significance codes: *** $p < 0.001$. ** $p < 0.01$. * $p < 0.05$.

Difference wave analyses

To allow a direct comparison between the effects found for the LexP and SubP conditions, I compared difference waves (i.e., the voltage difference between the congruent and the incongruent sentences per preposition type). The results below are presented per critical word, i.e., preposition and noun. The difference waveforms for the lexical and subcategorized prepositions are shown in Figure 5.6.

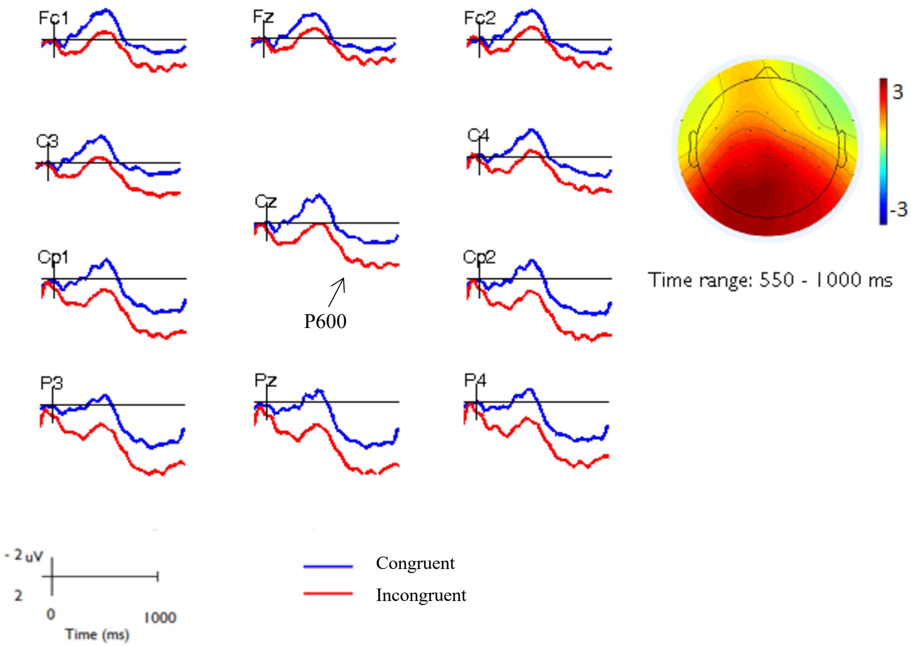

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Figure 5.5. Panel A shows grand average ERPs for congruent (blue line) and incongruent (red line) noun in sentences with subcategorized prepositions. The onset of the preposition is at 0 ms. Panel B gives topographical information for the P600 (time range: 550 – 1000 ms) effect.

The effects for the lexical and subcategorized prepositions were compared in three time windows. The analysis of the first window 100 – 250 ms revealed a statistically significant main effect of preposition type indicating that the ERP effects for these two types of prepositions differ (Table B-10, in Appendix B). In the second time window 300 – 550 ms also a main effect of preposition type was found (Table 5.5). In both time windows the amplitudes of the difference waveforms for lexical prepositions were more negative than those for subcategorized prepositions (cf. Figure 5.6). In the third time window 550 – 1000 ms the preposition type proved statistically significant too, showing that the difference waveform for the subcategorized prepositions is more positive relative to the waveform for the lexical prepositions.

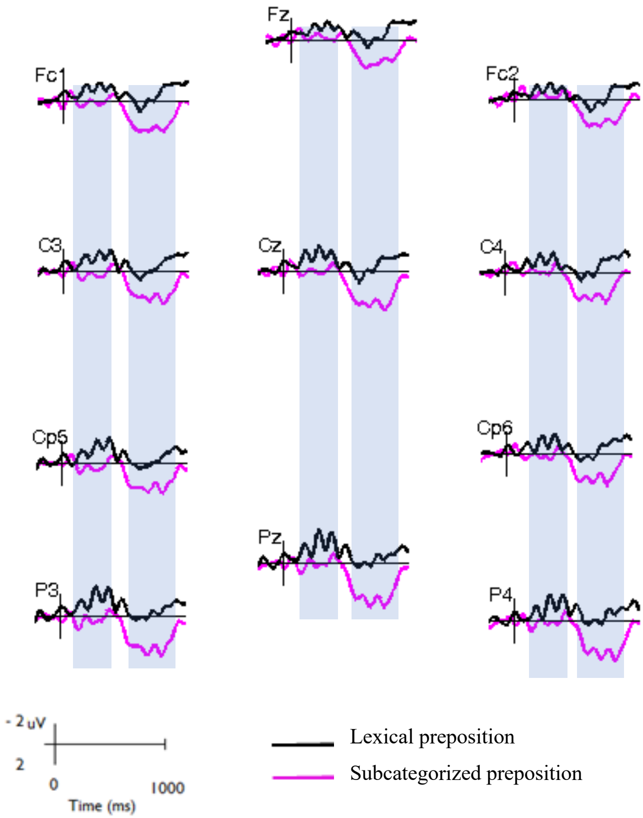

Figure 5.6. Comparison of difference waveforms for the lexical preposition (black line) and for the subcategorized preposition (pink line). The shaded areas show time windows that were analyzed. The first shaded area includes two time windows, 100 – 250 ms and 300 – 550 ms while the second shaded area shows the latency of 550 – 1000 ms.

Table 5.5. Brief summary with estimated effect sizes and significance levels of the LMM statistics for the difference waveforms relative to prepositions in LexP and SubP sentences (time windows: 300 – 550 ms and 550 – 1000 ms) and relative to nouns (time window: 550 – 1000 ms) in LexP and SubP sentences. The full statistical model is given in the supplementary materials (Tables B-11, B-12 & B-13, in Appendix B).

	Time window	Estimate	Std. Error	t-value
Preposition (in LexP vs. SubP)	300 – 550 ms	.12	.05	2.25*
	550 – 1000 ms	.4	.04	6.43***
Noun (in LexP vs. SubP)	550 – 1000 ms	.76	.07	9.91***

Significance codes: *** $p < 0.001$. ** $p < 0.01$. * $p < 0.05$.

In addition to the time windows for the prepositions presented in Figure 5.6, I also analyzed a late time window, namely, 550 – 1000 ms for the nouns in LexP and SubP sentences. The earlier time window of 300 – 550 ms was not included in this analysis since for the noun in SubP sentences the effect most probably interacts with the ERP effect from the preceding incongruent subcategorized preposition. A main effect of noun in each sentence type was found in the late time window demonstrating an amplitude difference between the two waves (Table 5.5). As shown by the ERP analyses presented above, the nouns in LexP and SubP sentences elicited qualitatively the same ERP effects, i.e., a P600. However, I found a statistically significant difference in amplitude for the difference waveforms with stronger positive effect for the nouns in SubP sentences. This outcome could suggest that quantitatively different processing took place (Gazzaniga, 1988). In addition, the preposition type by laterality interaction was statistically significant with the effect from SubP sentences more left lateralized than that from LexP sentences which was relatively symmetrically distributed (see topoplots in Figures 5.3 and 5.5 for nouns in LexP and SubP sentences, respectively).

5.5. Discussion

The aim of the present study was to test whether the processing of lexical and subcategorized prepositions in sentences would elicit qualitatively different ERP components and thus support the theoretical idea that prepositions can be classified as a hybrid between lexical and functional categories. This hypothesis was based on the theoretical assumption that these two types of prepositions can be used as lexical category words or as functional category words, depending on their linguistic contexts. Previous theoretical research suggests that depending on their context not all prepositions fit neatly into either lexical or functional category (Asbury, et al., 2008; Littlefield, 2006; Zwarts, 1997). Linear mixed model (LMM) analyses of ERP results revealed that indeed, as suggested by theoretical research, lexical and subcategorized prepositions in respective sentences are processed qualitatively differently. Specifically, lexical prepositions are processed more like lexical categories (e.g., Kutas & Hillyard, 1980; Friederici, Hahne, & Saddy, 2002), in that they elicit an N400 in violated or dispreferred contexts, whereas subcategorized preposition are processed more like functional categories eliciting a P600 when violated or dispreferred (e.g., Kaan, 2007; Kaan & Swaab, 2003; Bornkessel-Schlesewsky & Schlesewsky, 2009). As such, the study provides support for the view that (German) prepositions constitute a hybrid between functional and lexical categories.

Sentences with lexical prepositions

Two negative polarity shifts were elicited relative to the onset of lexical preposition – an N200 effect which had an even distribution over the scalp and an N400 more prominent in centro-posterior electrodes. These effects suggest that a contextually unexpected preposition was detected and the fact that an N400 was elicited shows that this expectancy was related to lexical-semantic processing (as opposed to structural requirements/expectations). Thus, the hypothesis that lexical prepositions are processed like other lexical categories was supported. Less expected than the classical (mostly visual modality) N400, I also found a negative polarity effect (N200) preceding the N400.

A number of studies have reported similar biphasic negativities during auditory sentence processing. In a series of studies Connolly et al. (1990, 1994) compared ERPs with sentence-final words in highly constraining sentence contexts such as *The king wore a golden crown* with ERPs in sentence contexts with low constraints such as *The woman talked about the frogs*. Words of low constraining sentences (i.e., frogs) elicited negative effects relative to words in highly constraining sentences (i.e., crown). Importantly, Connolly et al. (1990) reported that individual difference waveforms showed two distinct peaks, an early one with a central distribution (N200 effect) and a later one with a centro-parietal distribution (N400 effect). The authors suggested a tentative explanation in that the N200 reflects an acoustic analysis of the initial phoneme of the critical word, and the N400 a semantic analysis of the critical word, both of which are dependent on the contextual constraint of the sentence. Van den Brink et al. (2001) also found an early N200 effect followed by an N400 effect. The study used spoken sentences that ended with a word that was (a) congruent, (b) semantically anomalous, but beginning with the same initial phonemes as the congruent completion, or (c) semantically anomalous beginning with phonemes that differed from the congruent completion. In addition to the expected N400, an N200 was found to words which were semantically anomalous beginning with phonemes that differed from the congruent completion. Interestingly, in contrast to the N400, the N200 effect disappeared when the semantic anomaly shared the initial phoneme with the semantically expected word. The authors concluded that the N200 was related to the lexical selection process during which word-form information resulting from an initial phonological analysis and content information derived from the context interact. The consecutive N200 and N400 effects found in this study for the lexical preposition can be related to these previous studies. In this study, the N200 effect can also be explained as a mismatch of word-form resulting from an initial phonological analysis while the N400 is a more content related effect. Let's consider an example set of minimal pair sentences from our experiment *Der Mann trägt das Paket in/*bei einer Tasche* (the man carries the package in/*at a bag). Although the preposition *bei* (at, with, during) which has a temporal meaning, here is not semantically completely impossible and it can be correctly continued given the preceding context (e.g., *Der Mann trägt das Paket bei einem Überfall* (the man carries the package during an attack)), it is much less probable than the locative preposition *in* (in) as in the congruent sentence. This preference for *in* over *bei* was evidenced in our sentence completion rating pretest in which participants completed the experimental sentences after (both congruent and incongruent) prepositions and rated the difficulty of the task. For this specific example, the sentence completion average rating score for the congruent sentence with *in* was 1 while for the incongruent sentence with *bei* the average rating was 2,7 (on a scale from 1- very easy to 6- very difficult). The finding reported in this chapter is somewhat similar to Connolly et al.'s highly and low constraining contexts in which semantically valid words in low constraining context elicited processing effects (N200 and N400) because they did not satisfy the initial acoustic analysis of a word-form as well as the word semantics predicted by the sentential context. In the present study, although prepositions in the incongruent condition were also semantically correct, they were dispreferred or considered to be less likely based on the preceding context both on a semantic and on a phonological word-form level, hence leading to the observed N200 and N400 effects. Generally speaking, one can assume that since the number of prepositions in a language is very small, the expectancy for a specific preposition rises, which directly affects phonological and lexical-semantic processing (in contrast to e.g., nouns where the possibilities are often numerous). Therefore, many contexts will be highly constraining for specific prepositions and if this expectancy is not met, it affects processing.

As predicted for the noun in LexP sentences, I found an N400 effect in the incongruent condition with an even distribution over the scalp. Although N400 is usually strongest over centro-parietal regions (e.g., Hagoort & Brown, 2000), a component with a broader or more centralized distribution has also been found, especially in the auditory modality (e.g., Friederici et al., 2002). This effect is explained by the violation of semantic expectancy in the context of a preceding preposition. In the example above, *Tasche* (bag) after the preposition *bei* was processed as a semantic mismatch because *bei* has a temporal meaning in this case and *Tasche* (bag) cannot express time or a period of time like *Überfall*, for instance. Hence, the semantic mismatch between the preposition and the noun. One may ask why, like in the case of lexical prepositions, no earlier N200 effect was observed with nouns. The issue here is that first of all, I did not use highly constraining contexts for the nouns, so that there would be no strong expectation for a specific noun and therefore, its specific phonological form; next, even if an N200 effect did occur following the incongruent noun it would have overlapped in time with the N400 effect on the preceding preposition from which it could not have been disentangled. Furthermore, according to Hagoort (2008) these two components (i.e., N200 and N400) tend to overlap in time, which means that it is very hard to disentangle the two effects and find solid evidence showing that indeed the N200 and N400 effects are qualitatively distinct.

In addition to the N400 effect, LexP sentences elicited a P600 (or a late positivity) in the experiment presented here. Traditionally, this component has been observed in response to (morpho)syntactic violations (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2009). However, it has been found to be sensitive to non-syntactic information as well, representing an overall evaluation of well-formedness of a sentence (Roehm, et al., 2007). The P600 has even been associated with semantic anomalies ("semantic P600") (Bornkessel-Schlesewsky & Schlesewsky, 2009). The finding of the P600 effect in LexP sentences can be related to the results of Roehm et al. (2007) who found a biphasic N400-P600 effect to sentence final semantic anomalies. Similarly to the sentences used in the present study, the sentences in Roehm et al. (2007) were morphosyntactically valid. The authors interpreted this non-syntactic/structural occurrence of P600 as a global analysis of a sentence's well-formedness, which could explain the effect I found here as well.

Sentences with subcategorized prepositions

No negative components were found for the preposition in SubP sentences. For the noun in these sentences the early time window was not analyzed since any effect, if there was one, would overlap in time with the preceding effect on the preposition. Both the preposition and the noun elicited late positive components (P600).

In addition to a P600, subcategorized prepositions elicited a small positive effect in the time window of 300 – 550 ms. This positive effect could belong to the P300 family of ERP components. In language studies, a P300 has been reported to occur around 300 ms (Rösler et al., 1998) and later (Osterhout, 1992). This effect has been explained as reflecting "context updating" processes (Donchin & Coles, 1988). In our study, the occurrence of this early positive effect to subcategorized prepositions is open to interpretation.

A P600 effect emerged in relation to subcategorized prepositions. I interpret this P600 as a response to a structural unexpectedness during parsing. This effect can be related to parsing difficulties similar to those reported by Allen et al. (2003) who examined the effects of syntactic (inflectional) violations on verbs. In their experiments, auxiliary *will* predicted an infinitival verb form. Whenever the parser encountered the violation of this prediction, e.g., in **will wanted,* the suffix *-ed* rendered the structure incorrect, resulting in a P600 effect. Similarly, the specific verbs in our SubP sentences require, i.e., subcategorize for, a specific preposition and when the parser encounters the violation of this expectation a P600 effect emerges. Like the suffix *-ed* which is semantically virtually empty and fulfills the functional role of expressing past tense, the subcategorized prepositions in our study had hardly any semantic content and were inserted into the structure to fulfil the verb's requirements (case and thematic role assignment). Allen et al. (2003) found the effect on a bound inflectional morpheme. In our study, subcategorized prepositions did not directly attach to the preceding verb and were thus free-standing. These prepositions nevertheless had a strong bond with the verb and in this sense are not unlike bound morphemes. Note, however, that in our case, the prepositions in the incongruent sentences were not outright violations and the sentence could still have continued correctly. The effect is thus more likely that of a dispreferred form rather than that of a violation as in Allen et al. (2003).

A sentence-final P600 was also found following the nouns in SubP sentences. This effect could be interpreted as a global evaluation of the sentence well-formedness similar to the P600 effect on nouns in LexP sentences. However, this interpretation is more likely when a P600 is preceded by an N400 effect as in Roehm et al. (2007), for example. Since in this study it was not possible to establish the presence of an N400 preceding a P600 for the nouns in SubP sentences, one cannot tell whether there is a biphasic N400/P600 here as well. Another interpretation of the effect could be that the P600 effect following the noun represents structural/syntactic processing similar to that elicited after subcategorized prepositions.

Difference waveforms

To compare results of both types of sentences (LexP and SubP), I modeled the difference waveforms for each type of sentence in an LMM analysis. The analysis together with the visual inspection of the waveforms showed that the processing of lexical and subcategorized prepositions differed significantly at all time windows selected for analysis. This once more supports the theory that these prepositions show distinct linguistic behavior in their respective contexts and that the word class of prepositions can thus be characterized as being a hybrid between lexical and function categories. The important finding here is that when comparing lexical and subcategorized prepositions, the effects differ not only in amplitude but also in polarity – in case of lexical prepositions the effect is a negative-going shift whereas for subcategorized prepositions it is clearly positive. This once again confirms that qualitatively different processing took place. The difference waveform analyses of the nouns in LexP and SubP sentences also revealed amplitude differences showing that the qualitative difference in the processing of lexical and subcategorized prepositions is reflected on the nouns in their respective contexts as well.

Conclusion

The results reported in this chapter support theories proposing that the word class of prepositions is neither a purely functional nor a purely lexical category but forms a hybrid between the two categories. Depending on the context they appear in, they can be used like lexical or like functional category words. I showed that in lexical usage prepositions are processed like lexical category words (eliciting an N400), whereas in subcategorized usage they are processed like functional category words (eliciting a P600). Therefore, in terms of syntactic categorization, prepositions should be classed as a hybrid between lexical and functional categories.

Chapter 6.

Comprehension and production of prepositions in German-speaking children [10]

10 Chanturidze, M., Carroll, R., & Ruigendijk, E. (2019). Comprehension and production of prepositions by German-speaking children. In P. Guijarro-Fuentes, & C. Suárez-Gómez (Eds.), *Proceedings of GALA 2017: Language Acquisition and Development* (pp. 271-288). Newcastle upon Tyne: Cambridge Scholars Publishing.

Abstract

Phonologically and orthographically identical prepositions can exhibit properties of lexical (lexical prepositions) and functional (subcategorized prepositions) categories. Because of this functional ambiguity, prepositions represent an excellent category to study the acquisition of lexical and functional properties while keeping phonological material constant. Forty-six typically developing German-speaking children (age 6;6 – 13;2 years) and thirty adult controls (age 18 – 33 years) participated in the study. Comprehension of lexical and subcategorized prepositions was tested in an auditory *sentence acceptability judgment task*. For production participants performed contrastive elicitation tasks. Comprehension accuracy was higher for adult controls than for children, but improved in children as a function of age. No effect of preposition type or an interaction of group by preposition type was found. Performance in the production task was at ceiling in both children and adults. It was concluded that children's comprehension of lexical and subcategorized prepositions lags behind that of adults. I did not find support for the argument that lexical or functional properties of prepositions play a crucial role in the acquisition as no differences either in the comprehension or production of lexical and subcategorized prepositions were found. As children get older, i.e., from around 10 years, their mastery of prepositions becomes similar to that of adults.

6.1. Introduction[11] and research questions

In the current study the acquisition of different types of prepositions in TD children is addressed. Specific questions posed are whether there is a difference (a) in the comprehension and (b) in the production of lexical versus subcategorized prepositions in TD children. That is, is there a difference in the comprehension and production of these two types of prepositions despite identical phonological forms? Furthermore, how do the comprehension and/or production of lexical and subcategorized prepositions develop over age?

The comprehension of German prepositions in *a sentence acceptability judgement task* was examined, while the production data was collected in a *contrastive elicitation task with pictures*. Prepositions were tested in their lexical (i.e., lexical prepositions) and functional (i.e., subcategorized prepositions) use.

Based on earlier studies, such as by Grimm (1975) – who observed that children use incorrect prepositions in their functional use up to seven years of age – and by Friederici (1983) – who found that eight and nine year-old children found prepositions in their functional usage more difficult than prepositions loaded with meaning (i.e., lexical usage) (see chapter 2, section 2.2 for more details) – it was expected that (a) young children do not reach adult performance on comprehension and production of prepositions, (b) lexical prepositions are mastered earlier than the subcategorized ones both on comprehension and production, and (c) comprehension and production of prepositions improves as a function of age.

6.2. Method

For the specific design of the comprehension and production experiments and the sentence material used in this study, the reader is referred to Chapter 4, section 4.1 for the comprehension experiment and section 4.2 for the production experiment.

6.2.1. Participants

Forty-six TD children (16 female) participated in the study. All were monolingual speakers of German. The mean age of children was 9;6 years (range: 5;11 – 13;2 SD: 1;8 years). Since the main focus of the study was to examine the difference between lexical and subcategorized prepositions rather than the general acquisition pattern of prepositions (e.g., at what age the first prepositions appear and what are they), I chose to test children that are already able to use prepositions to an extent that prepositions

11 For a more detailed introduction to the topic of prepositions in the first language acquisition, please see Chapter 2, section 2.2.

can be tested in different functions (Grimm, 1975, Friederici, 1983). In addition to children, 30 adult German-native speakers[12] (16 female) served as a control group. The mean age of these adult participants was 24 years (range: 18 – 33; SD: 3;08 years).

Participating children's parents (or legal guardians) gave written informed consent prior to testing and children received age-appropriate thank-you gifts for participation in the experiment. Adult participants gave written informed consent prior to testing and received payment.

According to the audiometric screening I conducted, all children were hearing normally, i.e., having a pure tone hearing threshold of 20 dB Hearing Level (HL) or better frequencies between 125 and 8000 Hz. Furthermore, none had any neurological impairment, had experienced any neurological trauma, or used antipsychotic medications as reported by their parents (or legal guardians). The study was approved by the Ethics Committee of the University of Oldenburg and conducted in accordance with the declaration of Helsinki.

6.2.2. Procedure on the comprehension experiment

Stimuli were presented auditorily via two Genelec loudspeakers at 65 dBA RMS. Children listened to the sentences in a story context with an alien character who uttered German sentences. Children were told that the alien wished to improve her German and asked children to help her by pointing out sentences she said incorrectly. Half of the sentences that children listened to were not well-formed. Children's task was to identify the sentences which were not well-formed, or as the children were told "sounded strange in German", and thereby help the alien improve her language performance. The judgements were indicated by pressing a dedicated button on a button box. Each participant listened to all the sentences presented in 4 experimental blocks of 7 minutes. After each block they were given an opportunity for a break. A practice session of nine trials familiarized participants with the task. The order of the sentences was pseudo-randomized in two different lists to avoid order effects. The stimuli were recorded by one female speaker. The instructions were given both in written and oral form. Stimulus presentation was controlled using E-Prime 2.0 professional experimental software (PST, Sharpsburg, PA) (www.pstnet.com/products/e-prime/).

6.2.3. Procedure of the production experiment

Participants first saw a picture on screen which was described by the experimenter. The experimenter, who was a native speaker of German, presented sentences orally in a neutral intonation and at a normal speaking rate. Next, a second picture appeared on

12 The same group of adult participants who took part in the experiments described in Chapter 5.

the computer screen that children were asked to describe imitating the experimenter. Participants were instructed to produce the sentences at their own pace.

Participants' responses were recorded and classified as target (prepositions correctly describing the situation of the picture) or non-target (incorrect prepositions or omission of one) (for more detailed description of the scoring on this task, please see Chapter 4 on methodology).

6.3. Results

6.3.1. Comprehension experiment

For the comprehension data, generalized linear mixed models (GLMM) with logit link function were estimated using lme4:glmer (Bates et al. 2013). Two GLMMs were run with *participants* and *items* modeled as crossed random effects. The first GLMM included *group* (adults vs. children) and *sentence type* (i.e., sentences with lexical vs. sentences with subcategorized prepositions) as fixed factors. The second GLMM, which was run using only data from children, included *age*, which was centered via a z-transformation prior to inclusion in all models, and *sentence type* as fixed factors. The statistical analyses were conducted using R (R Core Team 2014).

Children's overall *accuracy* on the *sentence acceptability judgement task* was 82.4% (SD 13.5). Accuracy on LexP sentences was 83.1% (SD 13.3) and on SubP sentences 81.6% (SD 14.4). Adult controls' performance was 95% (SD 3.08) overall, 95% (SD 4.07) and 95% (SD 3.25) on LexP and SubP sentences, respectively (Figure 6.1).

The results of the GLMM analysis for the group effect on the *accuracy* is summarized in Table 6.1. GLMM with *group* and *sentence type* as fixed factors revealed a significant main effect of *group* with adults performing better than children overall (on both sentence types together). There was no effect of *sentence type* nor an interaction between *group* and *sentence type* (i.e., LexP vs. SubP), showing that neither adults nor children did better on one sentence type than on the other.

The results of the second GLMM analysis, which included only children and was conducted for the children's age effect on the accuracy, are summarized in Table 6.2. GLMM with *age* and *sentence type* as fixed factors showed a main effect of *age*, i.e., as children get older, they perform better overall (both on LexP and SubP), but there was no statistically significant interaction effect of *age* by *sentence type,* indicating no performance differences on *sentence type* depending on *age* (Figure 6.2). There was no main effect of *sentence type* either. Although not statistically significant, we can see in Figure 6.2 that there is a tendency for subcategorized prepositions to elicit lower scores than the lexical ones.

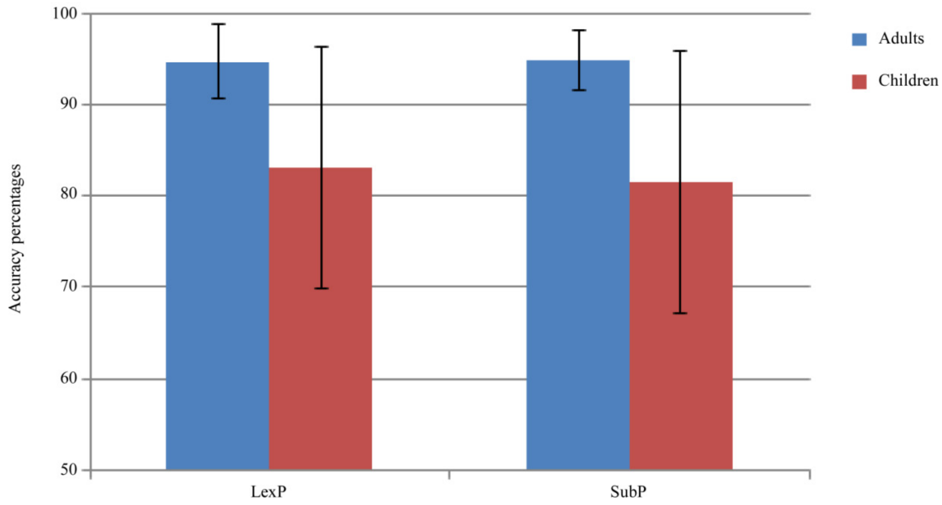

Figure 6.1: Performance on the comprehension task by children and adults. Red bars show accuracy percentages for children and the blue bars show percentages for the adult controls. LexP and SubP show results of sentences with lexical and subcategorized prepositions, respectively.

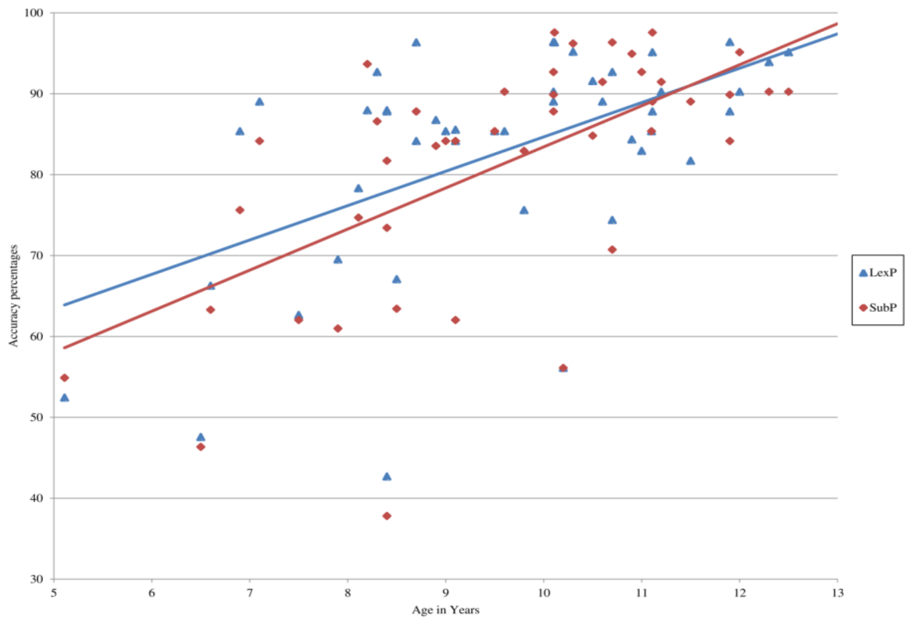

Figure 6.2: Children's age effect on comprehension accuracy. Blue triangles represent LexP sentences, red diamonds represent SubP sentences. LexP=sentences with lexical prepositions SubP=sentences with subcategorized prepositions.

Table 6.1. Results summary of the overall GLMM analysis of the effect of group on the accuracy performance of lexical and subcategorized prepositions.

Predictor				
Random effects:	Variance	Std. deviation		
Items (Intercept)	0.18	0.42		
Participants (Intercept)	0.60	0.78		
Fixed factors:	Estimate	Std. Error	z-value	p-value
Group (adults vs. children)	-0.69	0.09	-7.27	< .001
Sentence type	0.03	0.06	0.50	.62
Group x sentence type	0.04	0.03	1.13	.26

Sentence type= Sentences with lexical prepositions (LexP) vs. sentences with subcategorized prepositions (SubP).

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Table 6.2. Results summary of the GLMM analysis of the effect of age on the accuracy performance of lexical and subcategorized prepositions including only children.

Predictor				
Random effects:	Variance	Std. deviation		
Items (Intercept)	0.09	0.30		
Participants (Intercept)	0.39	0.62		
Fixed factors:	Estimate	Std. Error	z-value	p-value
AaT	0.59	0.10	5.85	<.001
Sentence type	0.06	0.05	1.20	.23
AaT x sentence type	-0.02	0.03	-1.72	.47

Sentence type= LexP sentences vs. SubP sentences.
AaT=Age at testing

6.3.2. Production experiment

Since performance on the production task reached ceiling effects both in adults and in children, no inferential statistics were conducted to avoid possible overestimation of the effects. On average, children correctly produced 98.5% of the lexical and 99.2% of the subcategorized prepositions on the *contrastive elicitation task I*, while on *contrastive elicitation task II* 94.0% of the sentences were produced correctly. Adults performed equally well, with 99.3% on lexical prepositions, 99.0% on subcategorized prepositions of the *contrastive elicitation task I* and 98.0% on *contrastive elicitation task II* (Figure 6.3).

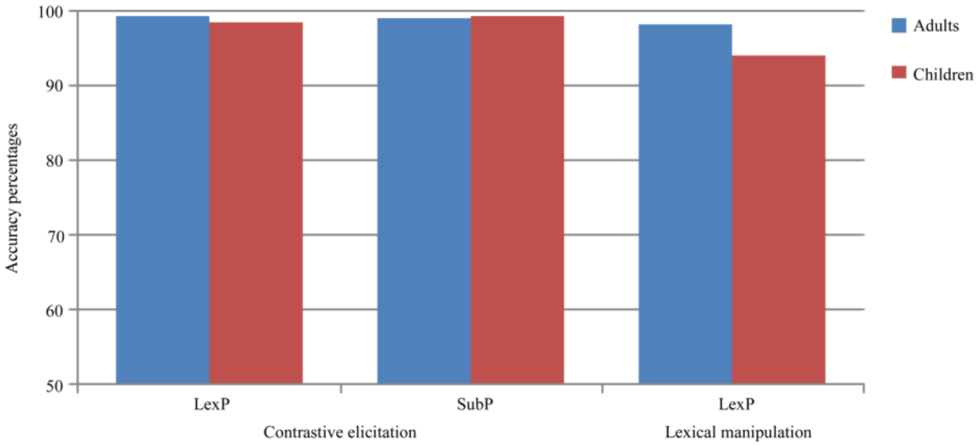


Figure 6.3: Performance on the production tasks by children and adults. Red bars represent accuracy percentages for children and the blue bars show percentages for the adult controls (LexP=sentences with lexical prepositions, SubP=sentences with subcategorized prepositions).

6.4. Discussion

As phonologically identical prepositions can exhibit properties of both lexical and functional categories, they represent an excellent class of words with which to study the acquisition of lexical and functional words while controlling for the phonological material. Despite this interesting property of prepositions in addition to their high frequency in language (Fang 2000), there has been little research regarding the acquisition of prepositions in TD children.

The aim of the present study was to examine the comprehension and production of lexical and subcategorized prepositions in German-speaking children. The question was whether children would perform better on one type of preposition than the other, both in comprehension and production. The underlying purpose was to see whether despite phonological similarity, there is a distinction in the acquisition of lexical and subcategorized prepositions due to their differences in linguistic features such as absence or presence of (semantic) meaning. Based on previous research (e.g., Grimm 1975), it was expected that as a group, participants of the study would perform better on lexical prepositions than on subcategorized ones. Furthermore, children's performance on comprehension and production of prepositions was compared to that of adult controls. The next question concerned the effect of age in the acquisition of these prepositions. The assumption was that children below 10 years would perform better on meaningful lexical prepositions than on virtually meaningless subcategorized prepositions both on comprehension and production. The children tested in the current study were older than in most studies on the acquisition of prepositions. Choosing to test children in a larger age range, the aim was to capture the acquisition trajectory of prepositions. Furthermore, testing an overall older age-group allowed me to test prepositions in different linguistics structures. From previous studies (e.g., Grimm 1975) we know that very young children, i.e., under four years have very limited or no knowledge of the different linguistic structure these prepositions occur in.

On the comprehension task, as expected, the GLMM analysis showed that children's performance as a group on both types of prepositions lags behind that of adult controls. However, closer inspection of the effect of age on the performance showed that older children, i.e., from around 11 years onwards (with a few exceptions) reach adult performance on the comprehension of both types of prepositions. Contrary to expectations, no difference was found between the comprehension of lexical and subcategorized prepositions in children (similarly to adults). This finding suggests that, at least when comparing adults against all children, the lexical/functional properties of prepositions do not play a crucial role. However, if one looks at the data of children below 10 years in Figure 6.2, one can see that there is much more variation in the performance and there is a tendency for subcategorized prepositions to elicit lower scores than the lexical ones. Hence, it could be that younger children (< 10 years) do show a difference in favor of lexical prepositions in the comprehension task, as suggested by Friederici's (1983) reaction time study. Although Grimm's (1975) study only tested spontaneous production of prepositions, she also found that children under the age of about 8 years showed more difficulties with subcategorized prepositions. I did not find strong statistical evidence for this difference in the comprehension of lexical and subcategorized prepositions in my data, which could be due to the fact that relatively few younger children participated.

Taken together, the results on the comprehension of lexical and subcategorized prepositions show that above 10 years of age on average children's mastery of both types of prepositions improves and at the age of 12-13 years reaches the adult-level. In addition, although there is a trend of younger children doing better on lexical than on subcategorized prepositions, clear statistical evidence that the comprehension of meaningless subcategorized prepositions is more difficult for children was not found, at least in the age range tested. However, the trend of better comprehension accuracy of lexical prepositions in younger children, suggests that in even younger children, for instance below 5 years, this difference can be more prominent.

Children performed very well on the production of both lexical and subcategorized prepositions. This outcome contradicts previous studies which have shown that prepositions with functional properties are more difficult than the ones with lexical properties for children. However, these earlier studies (e.g., Grimm 1975; Tomasello 1987; Littlefield 2006) examined prepositions in much younger children than in this study and this difference in age may have caused the difference in the results on the production of prepositions. The high performance on production could furthermore suggest that there is an asymmetry between comprehension and production of prepositions in favor of production. Although the general tendency in language acquisition is that comprehension precedes production, research on language acquisition shows that the reversed pattern is also possible (Hendriks and Koster 2010). Although the data seem to suggest that children perform better on the production than on the comprehension of prepositions, the conclusion that children are better on production than on comprehension cannot be made. One main reason is that the experiments conducted for this study were not designed to compare comprehension and production of prepositions directly. For example, while in the comprehension experiment children had to process a specific given preposition, on the production experiment they were less restricted to producing specific prepositions they could use an alternative preposition that correctly described the picture and hence had more freedom in choice of preposition on the production than on the comprehension experiment. To answer the question concerning the difference between the comprehension and production of prepositions, a further study is needed which will directly compare the two in more comparable experimental settings.

Conclusion

I conclude that children younger than 11 years have not yet reached adult performance level on the comprehension of lexical and subcategorized prepositions. Moreover, at least in the age group tested, meaningful lexical prepositions are not easier to comprehend than virtually meaningless subcategorized ones. There seems to be no difference in the acquisition of lexical vs. functional properties of prepositions as no differences either in the comprehension or production of lexical and subcategorized prepositions were found.

The production results seem to suggest that children at the ages tested have mastered the production of both types of prepositions as well as adults. However, a more demanding experiment, e.g., restricted to eliciting specific prepositions, has to be designed to support this finding.

Chapter 7.

Processing of prepositions in German-speaking children: an ERP study [13]

13 Parts of this chapter are based on: Chanturidze, M., van Rij-Tange, J.C., Carroll, R., & Ruigendjik, E. (in preparation). Processing of Prepositions in German-speaking Children: an ERP Study.

Abstract

Processing of twelve mono-syllabic German prepositions in lexical (lexical prepositions, e.g., *on the table*) and functional (subcategorized prepositions, e.g., *waiting for*) use was investigated in an ERP study. Twenty-four monolingual German-speaking TD children aged 6- to 13 years listened to sentences containing lexical and subcategorized prepositions. Both types of prepositions were presented in either congruent or incongruent sentence contexts. In addition, a set of sentences not containing any prepositions was used in the experiment. Half of these control sentences had sentences-final nouns which were incongruent in the preceding context. For the statistical analysis of the ERP data, generalized additive mixed modeling (GAMM) was applied. Contrary to adult participants who displayed an N400 in association to incongruent lexical prepositions and a P600 to incongruent subcategorized prepositions, children did not show processing effects in relation to incongruent prepositions either in lexical or functional use. However, comparison of the sentences with lexical (congruent + incongruent) vs. subcategorized (congruent + incongruent) prepositions yielded significant processing differences. A "classical" N400 effect was elicited in relation to the incongruent sentence-final nouns in the control sentences. These processing results obtained from TD children suggest that although children's processing of lexical-semantic violations of nouns (the word typically tested in ERP studies) results in an N400 similarly to adults, the processing of prepositions either in lexical or functional use is deviant from that of adults.

7.1. Short introduction and research questions

One of the goals of this thesis is to examine how the developing brain processes prepositions in lexical (lexical prepositions) and functional (subcategorized prepositions) use. In Chapter 6, children's offline processing of prepositions in lexical and functional use was reported. The offline processing study revealed that children, especially younger ones (< 10 years), perform worse on judgment of the well-formedness of sentences with congruent and incongruent lexical and subcategorized prepositions than adults do. Furthermore, no difference between the accuracy performance of lexical vs. subcategorized prepositions was found. To extend our understanding of the processing of lexical and subcategorized prepositions in children further, an ERP study of the processing of prepositions was designed.

In this online ERP study of prepositions in congruent and incongruent sentence contexts, the aim was to find out whether the developing brain, similarly to the adult brain (Chapter 5), shows a distinction in neurophysiological processing between two uses of prepositions, namely, lexical (lexical prepositions) and functional (subcategorized prepositions). As evidenced in Chapter 5, in adults the violations to lexical prepositions elicited an N400 – a component typically associated with lexical-semantic processing, whereas the violations to subcategorized prepositions elicited a P600 – a component typically associated with structural/syntactic processing. In addition to lexical and subcategorized prepositions, the study also measured the processing of sentence-final nouns following each type of preposition. In both cases, P600 effects were elicited. In addition to the positive effect, nouns in the context of incongruent lexical prepositions elicited an N400 effect. As for the present study with children, the research question posed was – how does the developing brain process prepositions in lexical and functional use? In other words, does it show a similar distinction between the two uses of prepositions as was shown for adults?

Although we know from past electrophysiological studies that children display distinct ERP patterns to syntactic and to lexical-semantic violations in sentence contexts from a young age, these studies are mostly limited to processing of nouns and verbs (Silva-Pereyra, Rivera-Gaxiola & Kuh 2005). Therefore, it is not known whether the developing brain generates different ERPs for violations when processing prepositions, similarly to the adult brain. Because children were able to judge congruent and incongruent sentences (both with lexical and subcategorized prepositions) mostly accurately offline, it is possible that the processing effects for incongruence are observed online as well. One could also hypothesize that children will not show a processing distinction between lexical and functional use of prepositions, taking into account the outcomes of the behavioral offline study in which no difference in accuracy performance was found between lexical and subcategorized prepositions.

In her experimental study, Grimm (1975) argued that all prepositions are initially processed as lexical (having meaning) by children and only later is the non-conceptual, more functional use of prepositions discovered. Given this evidence, children could show a lexical-semantic N400 when processing violations of both uses of prepositions. As discussed in the introductory chapter of this thesis, prepositions are not salient in the flow of speech because they are short and typically do not receive stress. Dube et al. (2019) reported that 9- to 11-year-old children were more sensitive to the perceptually more salient errors of commission (i.e., superfluous -s) evidenced by an ERP effect, whereas less salient errors of omission (i.e., absent -s) showed no such effect. The authors concluded that the relative perceptual salience of experimentally manipulated linguistic elements can influence processing in children. It would also be reasonable to assume that, because prepositions are typically less perceptually salient than for example, nouns and verbs, children will not show processing effects to incongruent prepositions or if they do, they could be delayed.

To sum up, so far it is unclear how children process lexical and subcategorized prepositions in incongruent sentence contexts. Several outcomes are possible, (1) children will show roughly the same processing effects as adults did. In the literature evidence has accumulated that children from the age of 10 to 12 years show adult-like ERP processing effects. Since most children in the current sample are around that age, one could expect that they will show a processing distinction between lexical and subcategorized prepositions similar to adults, (2) because we saw in the behavioral study with the same lexical and subcategorized prepositions that children were significantly less accurate than adults, one could also assume that ERP processing will differ between adults and children in important ways, for example, both uses of prepositions will be processed similarly, or (3) children will not show processing effects to incongruent prepositions as these words are perceptually not salient.

7.2. Method

To examine the ERP processing of congruent and incongruent lexical and subcategorized prepositions, stimuli of the comprehension experiment were used. For the comprehension experiment and the stimuli used in this study see Chapter 4, section 4.1. For detailed information regarding ERP methodology and the EEG recording and data analysis see sections 4.3 and 4.4, respectively in Chapter 4.

7.2.1. *Participants*

EEG data were analyzed from twenty-four children (9 female). The mean age of these children was 10;2 years (range: 6;9 – 13;2, SD: 1;6 years). Initially, thirty-seven monolingual German-speaking children participated in the study, a subset of children participating in the study reported in Chapter 6. This subset of twenty-four children was left after excluding children (*n*=4) whose accuracy scores on the sentence judgment task were not significantly above chance level. The cutoff for chance performance was determined by binomial test ($P_{correct}$ = 0.5, n=164, α = 0.05) to be 93 (out of 164) items correct (56.7%). A further 9 children were excluded because they were not able to sit quietly during the EEG recording session (e.g., they fidgeted, moved and blinked their eyes too much) and as a result their data was too contaminated with artefacts to be included in the analyses. The data from the thirty adult German-native speakers (16 female) from the study in chapter 5, were used as a baseline for comparing the processing effects in children. The mean age of the adult participants was 24 years (range: 18 – 33; SD: 3;08 years). Children's processing effects were not directly compared to those of adult participants (from Chapter 5). Two distinct statistical methods were employed for analyzing the data from child and adult participants. This difference in the analyses was necessitated by the specificity of the data in each case. For the details on this issue, see section 7.3. In this study, the processing effects found in adults (Chapter 5) were used as a standard processing of prepositions. All participants (children and adult controls) were right-handed according to a German adaptation of the Edinburgh Handedness Inventory (Oldfield, 1971).

Participating children's parents (or legal guardians) gave written informed consent prior to testing and children received age-appropriate thank-you gifts for participation in the experiment. Adult participants gave written informed consent prior to testing and received payment.

According to parent-reports on the questionnaire, all of the children were hearing normally, none had any neurological impairment, had experienced any neurological trauma, or used antipsychotic medications. The study was approved by the Ethics Committee of the University of Oldenburg and conducted in accordance with the declaration of Helsinki.

7.2.2. *Procedure*

The procedure of the ERP experiment with children was similar to the procedure of the ERP experiment with adults as described in Chapter 5. After the EEG cap was mounted, the children were seated in a sound attenuated booth in front of a computer screen. Sentences were presented auditorily via two Genelec loudspeakers at 65 dBA RMS. Children were asked to avoid eye-blinks and other movements during sentence presentation. In case of children, the division of the experiment into the number of blocks and the length breaks was different from the adult study. The experiment with children was divided into 4 blocks of 6 minutes each (instead of 8 with adults) and children were given an opportunity for a break of maximally 10 minutes after each block. To ensure concentration, participants were instructed to perform a *sentence acceptability judgement task* of the sentences from the comprehension experiment; they had to identify whether a sentence made sense by pressing a dedicated button on a joystick (red for senseless and green for sensible sentences). Each trial began with the presentation of a fixation cross for 700 ms followed by presentation of a sentence while the fixation cross remained in the center of the screen. After sentence offset, the cross was replaced by a question mark indicating a request for judgement via button press. A practice session of nine trials familiarized participants with the task. Experimental sessions, including electrode application, lasted 1.5–2 hours. The order of the sentences was pseudo-randomized in two different lists to avoid order effects. The stimuli were recorded by one female speaker, while the instructions were given both in written and oral form.

Stimulus presentation was controlled using E-Prime 2.0 experimental software (PST, Sharpsburg, PA) (www.pstnet.com/products/e-prime/).

7.3. Statistical Analysis

For statistical modeling of ERPs generalized additive mixed modeling (GAMM) was used (Lin & Zhang, 1999; Wood, 2006, 2011) using R v3.6.1 (R Core Team, 2014) and package mgcv v1.8-28 (Wood et al., 2011). GAMM estimates the relation between a dependent variable and a number of predictors similarly to typical regression methods. However, unlike typical linear regression in which the relation between a dependent variable and a predictor/covariate has to be linear, in GAMM this relation (between dependent variable and predictor) is modeled as a *smooth* function, which can, but does not have to be linear (van Rij et al., 2019) (for more detailed discussion smooth functions see Wood, 2017a). Here the smooth can be thought of as a continuous, potentially wiggly but not abruptly changing line that is expressed over time. As implemented in mgcv, smooth functions are constructed as weighted sums of sets of base functions that together form a smooth function. These base functions can be polynomials, but the default for one-dimensional smooth functions in mgcv are so-called thin plate regression splines. These splines have optimal properties for fitting unknown functions, i.e., the unknown and nonlinear pattern of the data (for more information, see Wood, 2017a, Chapters 4 and 5). Penalized regression (or more precisely, penalized iteratively re-weighted least squares [PIRLS]) is used to obtain maximum likelihood estimates of the smooths. In the present study smoothing parameters were estimated using fast restricted maximum likelihood (fREML) estimation (Wood, 2011) to avoid overgeneralization and overfitting of the data. In addition to widespread use in ecology (e.g., Pedersen et al. 2019) GAMMs have previously been used to model/analyze pupil dilation data (Lõo et al., 2016; van Rij, 2012; Vogelzang et al., 2016; van Rij et al., 2019). Most importantly, GAMMs have also successfully been applied for the analysis of event-related potentials (ERPs) measured by electroencephalography EEG (e.g., Boehm, van Maanen, Forstmann, & van Rijn, 2014; Nixon,van Rij, Li, & Chen, 2015; Tremblay & Newman, 2015).

We know that ERPs can vary in a number of different parameters, including the shape of the response, its latency and its amplitude. Standard statistical tools such as AN(C)OVA and linear regression allow only linear relationships between the dependent variable and the predictors. While such methods are often adequate for analyzing the data where only latency or amplitude varies (for example, data from adult participants such as in Chapter 5), they cannot fully model data where either the shape of response or both latency and amplitude vary (i.e., the data from child participants presented on the current chapter). GAMMs, on the other hand, are particularly well-suited for analyzing ERPs since they can model non-linear effects. Another issue with standard statistical analysis for ERP data is that it is standard practice to average the signal in a predefined time windows of interest. This may not only lead to a loss of power, but also means that possible latency differences between individuals can no longer be captured. GAMMs can resolve these issues by assessing the complete (non- linear) effect of time on the ERP signal.

For each participant and timestamp the average across trials was calculated per condition and per electrode (F7 F3 Fz F4 F8 Fc5 Fc1 Fc2 Fc6 C3 Cz C4 Cp5 Cp1 Cp2 Cp6 P7 P3 Pz P4 P8 O1 Oz O2) and these averages were modeled using GAMMs. The age effect was not included in GAMMs, as the signal-to-noise ratio was too poor to meaningfully assess this effect. Electrodes and layout used in the data analysis are shown in Figure 7.1 below.

In all of the analyses applied in this study

- the first electrode analyzed was Pz and subsequently the same analysis was used for the rest of the electrodes. Pz was chosen as for the initial analysis because most of the effects for the same stimuli in adults were observed in posterior regions (Chapter 5). Evidence from ERP studies in children suggest that they recruit the same brain regions as adults (Friederici, 2006).
- the dependent variable was ERP activity for each electrode.
- the model was first run without a first-order autocorrelative (AR1) error model.

Next the estimated autocorrelation of the residuals from the fitted model was extracted and the model was run again with this estimate as a starting value for the AR1 error model.

- as the data were heavy-tailed, the model was fitted using a scaled *t* distribution (Wood, Pya & Säfken, 2016) rather than a normal distribution.

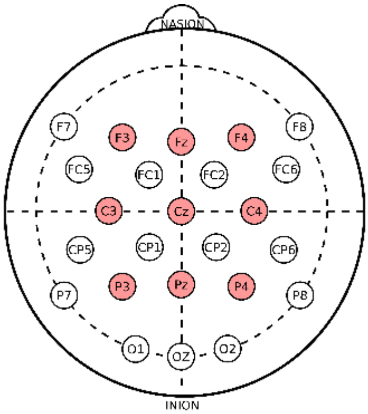


Figure 7.1. The lay-out of electrodes analyzed in the study.

7.4. Results

7.4.1 Behavioral results

In chapter 6, I reported children's accuracy outcomes on the judgement of congruent and incongruent lexP and SubP sentences. The subset of the children whose data was used for the ERP study, showed roughly the same accuracy patterns. The overall accuracy on the *sentence acceptability judgement task* was 87.9% (SD 7.1) on LexP and 86.4% (SD 8.7) on SubP. Accuracy for the control sentences reached 72.6% (SD 11.5). Both accurately and inaccurately rated trials were included in the analysis.

7.4.2. ERP results

Control sentences

The first analysis was run to verify whether there was an N400 effect in the control sentences (sentences without prepositions). The critical word was the final noun which was embedded either in a congruent or incongruent sentence context.

First, model comparisons were applied to test for an N400 effect. The first model included *congruency* (main effect) as a factor (congruent vs incongruent), the *time* by *congruency* interaction as a smooth (i.e., separate group-level 1-dimensional smooths for the congruent and incongruent conditions), and random smooths for *time* by *congruency* for each participant. The model was as follows:

```
m1R <- bam(Pz ~ congruency + s(time.in.ms, by=congruency, k=20, bs="ad")
        + s(time.in.ms, id, by=congruency, bs='fs', m=1, k=20),
        data=subdat, discrete = TRUE, family='scat',
        AR.start = subdat$start.event, rho=m1rho)
```

The second model was constructed excluding the interaction between *time* and *congruency* and the model was as follows:

```
m2 <- bam(Pz ~ congruency + s(time.in.ms, k=20)
        + s(time.in.ms, id, by=congruency, bs='fs', m=1, k =20),
        data=subdat, discrete = TRUE, , family='scat',
        AR.start = subdat$start.event, rho=m2rho)
```

7

In this second model there were no separate smooths for congruent and incongruent conditions, but instead one smooth over time for all trials.

Comparison of the two models suggested that the interaction is significant ($\chi2(2)$=2358.8, p<.001, ΔAIC=708.7). In other words, separate smooths for the congruent and incongruent conditions improve model fit. However, as the model was fitted with fREML (restricted maximum likelyhood) rather than ML (maximum likelihood), model comparisons were not reliable for comparing fixed effects (e.g., Faraway, 2016). As a result, another method was employed to test whether the nonlinear interaction is significant: the factor *congruency* was modeled with a binary predictor, and included the (potentially nonlinear) difference between congruent and incongruent items over time in the model.

The model specification was:

```
m3R <- bam(Pz ~ s(time.in.ms, k=20)
        + s(time.in.ms, by=Incongruent, k=20)
        + s(time.in.ms, id, by=congruency, bs='fs', m=1),
        data=subdat, discrete = TRUE, family='scat',
        AR.start = subdat$start.event, rho=m3rho)
```

The summary statistics revealed that there was a significant difference between the ERP of the congruent and incongruent subject averages (F(4.558, 5914.161)=2.66; *p*=0.019). Figure 7.2 below illustrates the differences between the estimates of the difference wave at Pz from model m1R (categorical predictor) and m3R (binary predictor).

As can be seen from Figure 7.2, the difference between congruent and incongruent conditions was significant in the best fitting model with binary predictors. The effect is negative going and occurs between 400 and 650 ms following the critical stimulus onset (sentence final noun). The trustworthiness of these models was verified by plotting the residuals which verified that the model provides a reasonable fit of the data (the plots are given in Appendix C, Figure C-1). The difference is not significant between congruent and incongruent sentences in the best-fitting model with categorical predictor (left panel).

Having done the analysis for electrode Pz (Figure 7.2), the same analysis was applied for the other electrodes. Besides Pz, significant differences were found for electrodes C4, P4, O1, Oz, and O2, which can be seen in Figure 7.3 below, which displays estimated activities in relation to the sentence-final nouns in the control sentences (for the actual ERP activity at all electrodes see Appendix C, Figure C-2)[14].

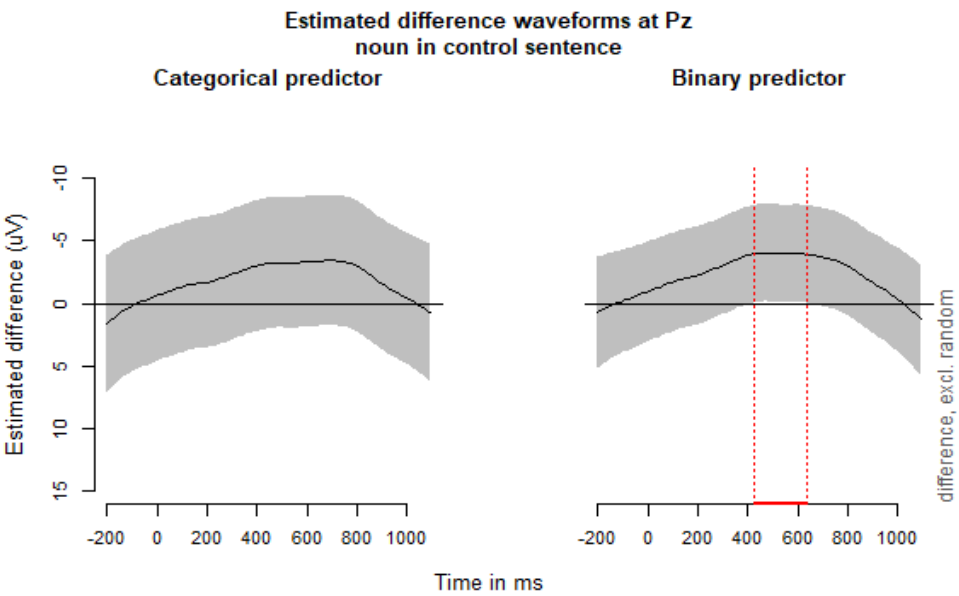


Figure 7.2. Both in the left and right panels the difference waveforms of congruent and incongruent sentences are plotted. Intervals where the difference is significant are indicated with red lines. The left panel shows the difference extracted from the best-fitting model with categorical predictor (m1R), i.e., the difference between the smooth for congruent and the smooth for incongruent. The right panel shows the difference based on the model with binary predictors (m3R), i.e., the smooth of the difference between congruent and incongruent. Grey shaded areas represent 95%-confidence intervals around the estimated difference.

14 The figures with estimated activities are given in the main text, whereas the grand average ERP plots can be found in the Appendix. This was done on the ground that the statistical analysis discussed in the chapter was conducted on the estimations. Therefore, the reader has the visualization of the statistical data at hand and is referred to Appendix for actual ERP activity.

Furthermore, the difference in congruency in topography in the N400 window (450-550 ms after noun onset) was analyzed. This time window was selected for the topographical analysis because the N400 elicited for the nouns in the control sentences included this time interval (450-550 ms) in all (but C4) electrodes (Figure 7.3). However, no significant difference in topographical distribution was detected (Figure 7.4).

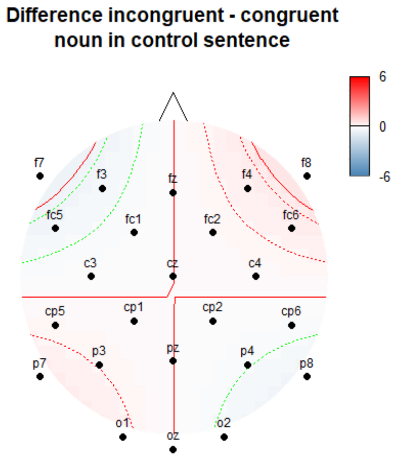


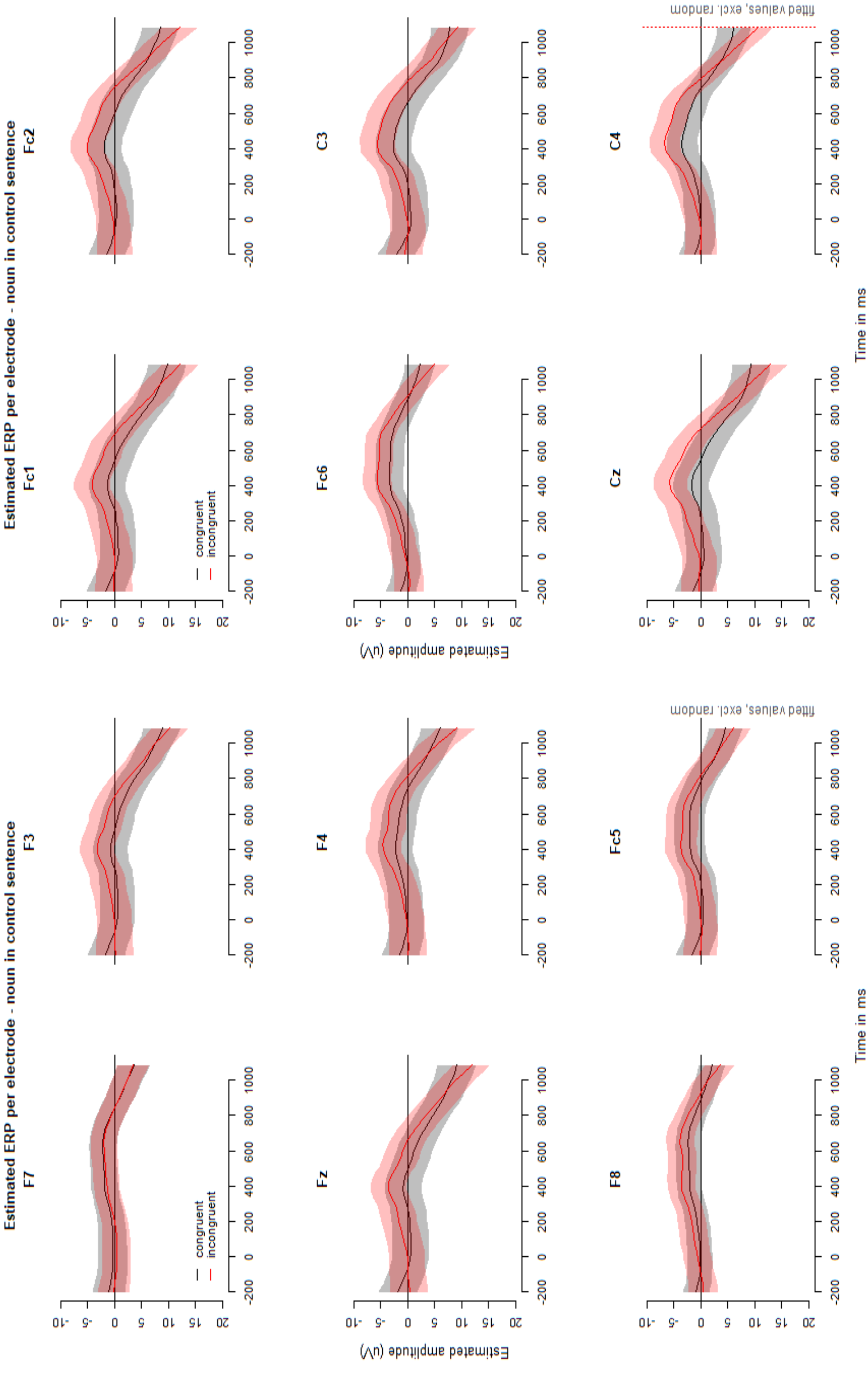
Figure 7.4. Topographical distribution of the amplitude difference between congruent and incongruent control sentences in the time window 450-550ms following the onset of the sentence-final noun.

Experimental sentences

As described in the methodology Chapter 4 of this thesis, two critical words were triggered in the experimental LexP and SubP sentences, namely the preposition and the noun following the preposition. Examples of the experimental sentences are reproduced in Table 4.1 below.

Table 4.1. Example sentences of the preposition types and congruent and incongruent sentences. Critical words for the ERP analyses are underlined.

	Lexical	Subcategorized
Congruent	Der Bauer schiebt die Kuh *in* einen Stall. “The farmer shoves the cow into the stable.“ Der Bär klaut den Honig *aus* einem *Nest*. “The bear steals the honey from a nest.”	Der Uhu sucht *nach* einer Maus. “The owl looks for a mouse.“ Das Mädchen sorgt *für* eine *Puppe*. “The girl takes care of a doll.”
Incongruent	*Der Bauer schiebt die Kuh *für* einen *Stall*. “The farmer shoves the cow for the stable.“ *Der Bär klaut den Honig *zu* einem *Nest*. “The bear steals the honey to a nest.”	*Der Uhu sucht *von* einer *Maus*. “The owl searches from a mouse.“ *Das Mädchen sorgt *in* eine *Puppe*. “The girl takes care in a doll.”


Estimated ERP per electrode - noun in control sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random
Estimated ERP per electrode - noun in control sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random

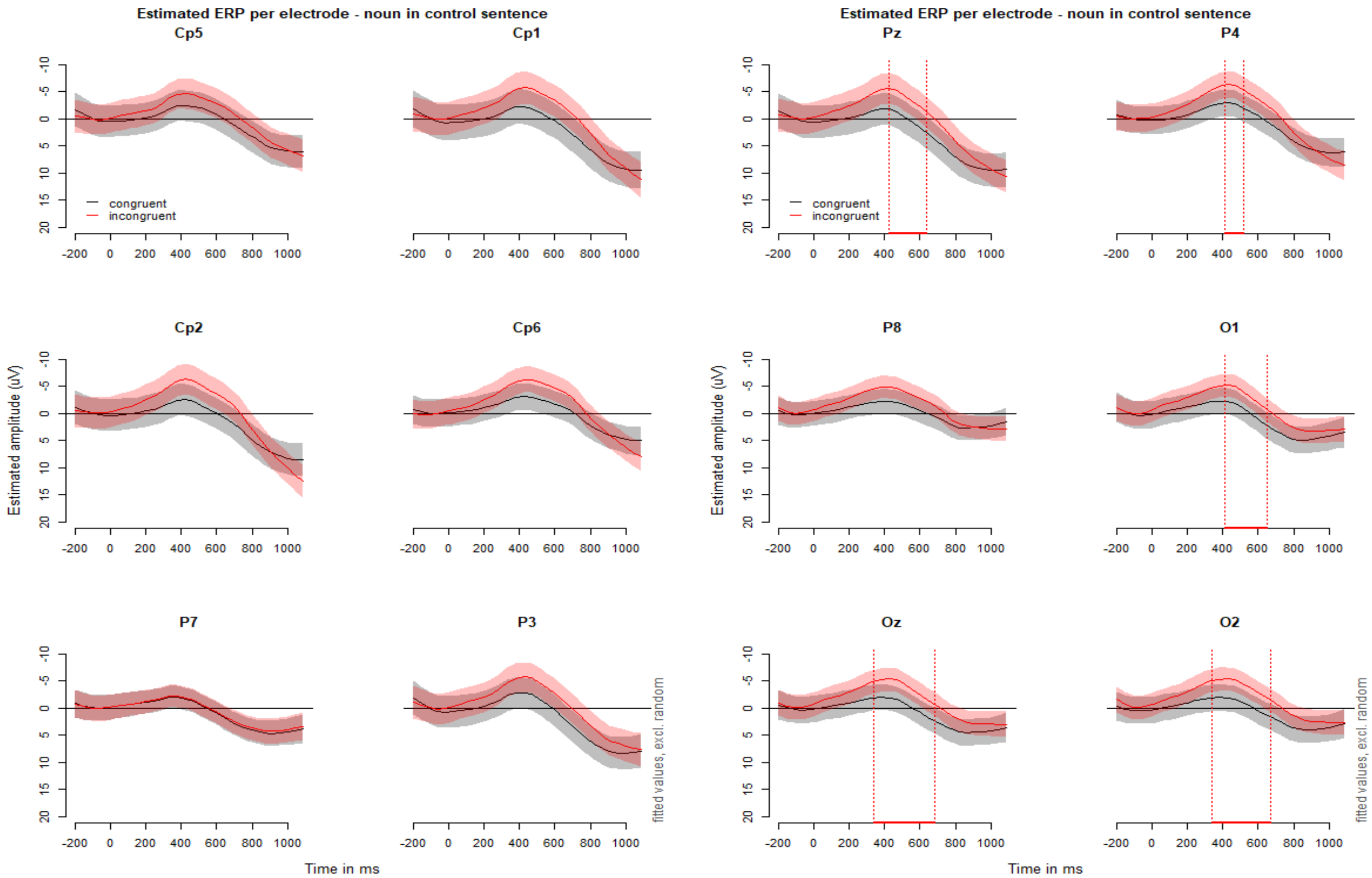


Figure 7.3. (next two pages) Estimated ERP at all electrodes for the nouns in the control sentences. Intervals where the effect was significant is marked with red dotted lines.

LexP sentences – Prepositions

Similarly to the control sentences, the congruency effect was tested for Prepositions in LexP sentences. Since in the analysis of the control sentences I settled on the method with binary predictors, the same method was used here as well. The model was as follows:

```
m1R <- bam(Pz ~ s(time.in.ms, k=20)
        + s(time.in.ms, by=Incongruent, k=20)
        + s(time.in.ms, id, by = congruency, bs='fs', m=1),
        data=subdat, discrete = TRUE, family='scat',
        AR.start = subdat$start.event, rho=m1rho)
```

The model includes the activity at a specific electrode as a dependent variable and congruency as a two-level predictor and the interaction between time and congruency. No main effect of Congruency (F(2.786, 5961.656)=0.869; p=0.5) relative to prepositions in LexP sentences was observed at the electrode Pz (Figure 7.5).

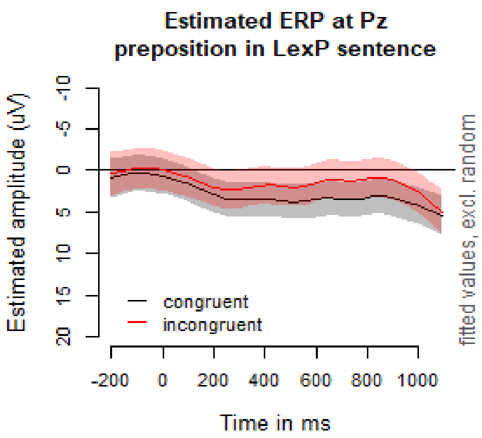
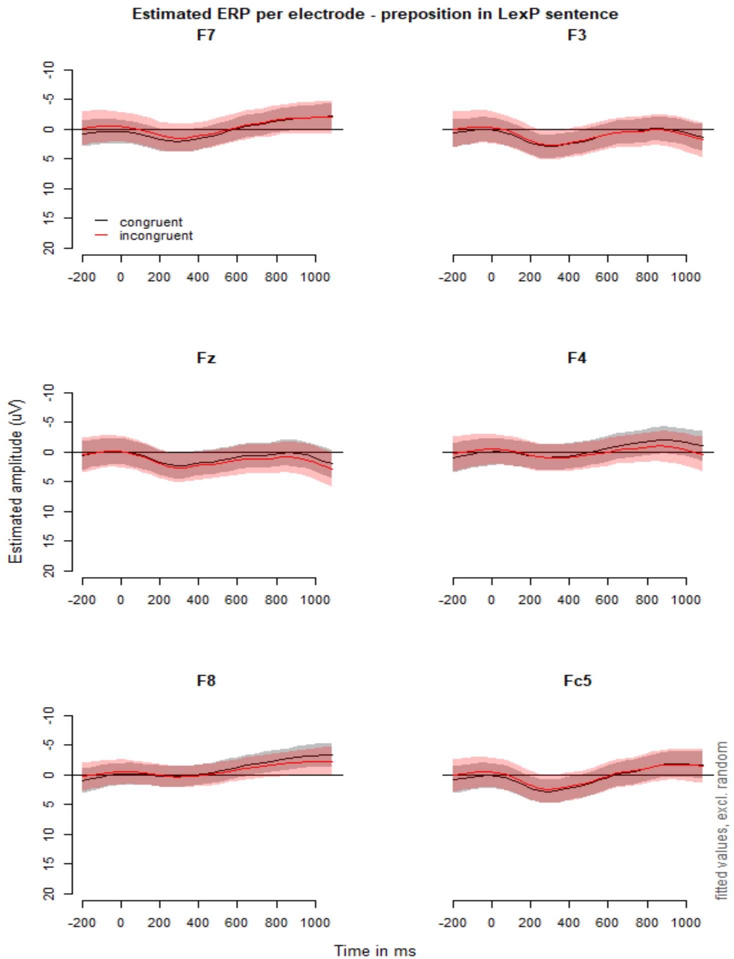
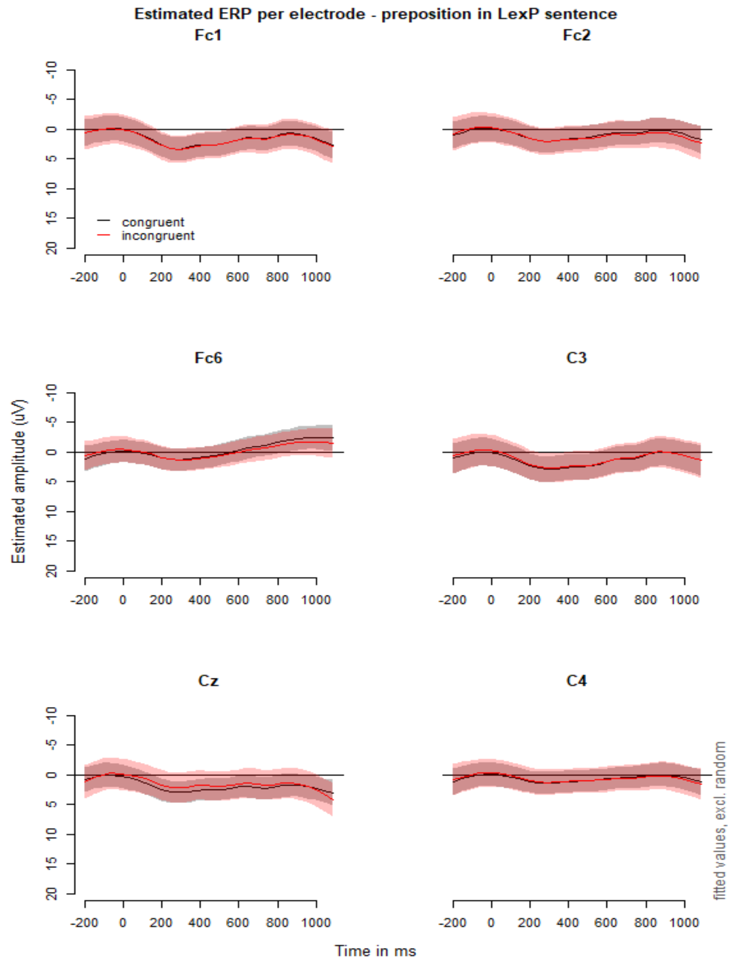


Figure 7.5. Activity at Pz electrode relative to a preposition in LexP sentences. The black line depicts activity of the congruent trials and the red line shows the activity for the incongruent trials.

Subsequently, the same analysis was applied to the rest of the twenty-four electrodes, which yielding a main effect of congruency with a negative going waveform at only two electrodes, namely, Oz and O2 (Figure 7.6). Because the congruency effect reached significance only at two electrode sites (out of twenty-four), this outcome cannot be reliably considered as an ERP effect. The grand average ERP activities at all electrode sites are given in Appendix C, Figure C-3.


Estimated ERP per electrode - preposition in LexP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random


Estimated ERP per electrode - preposition in LexP sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random

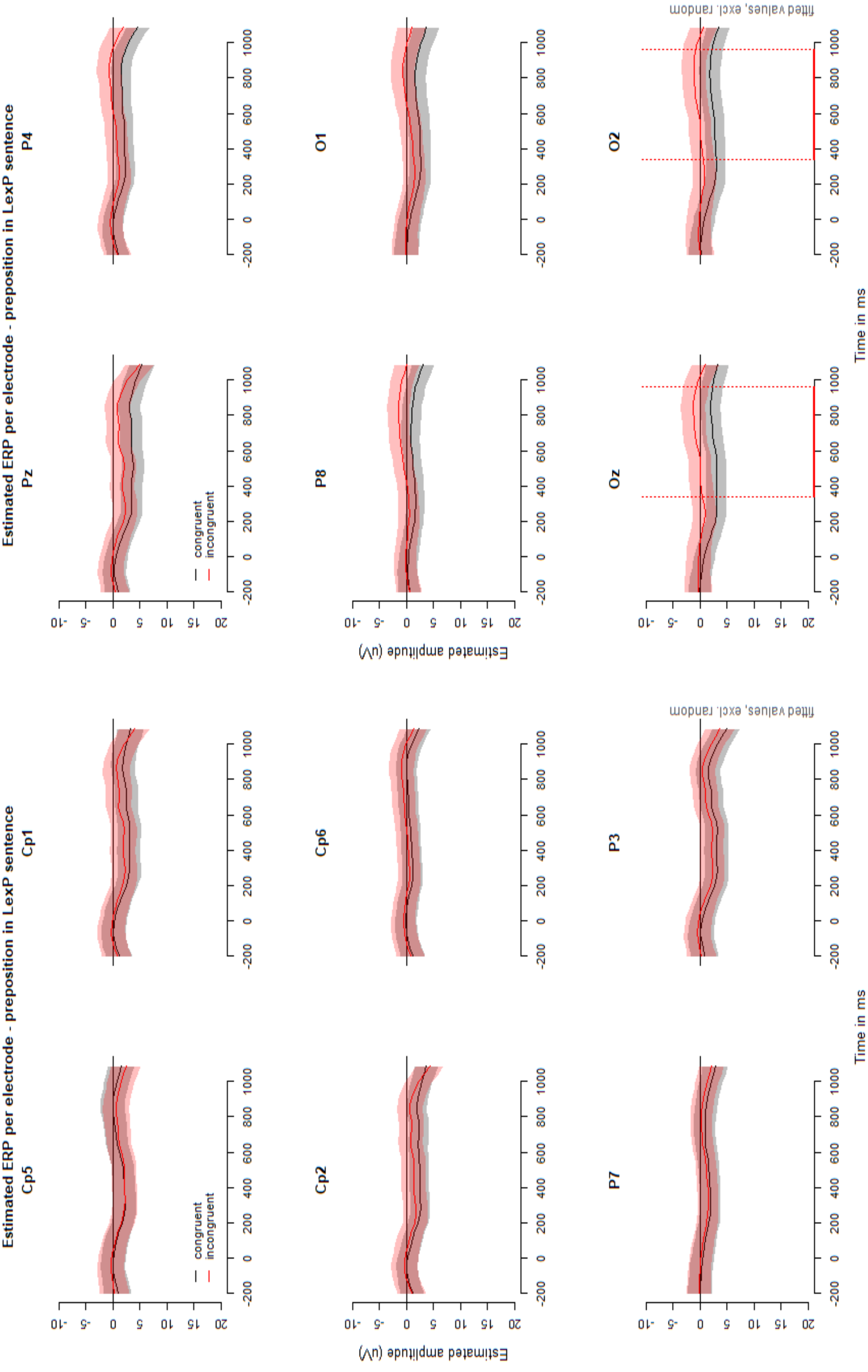


Figure 7.6. Estimated ERP at all electrodes for the prepositions in LexP sentences. Intervals where the effect was significant is marked with red dotted lines.

Next, the difference in congruency in topography in the N400 window (450-550 ms after preposition onset) was tested but no significant differences were observed ($F(1.001, 1094.629) = 0.057$, $p = 0.811$) (Figure 7.7).

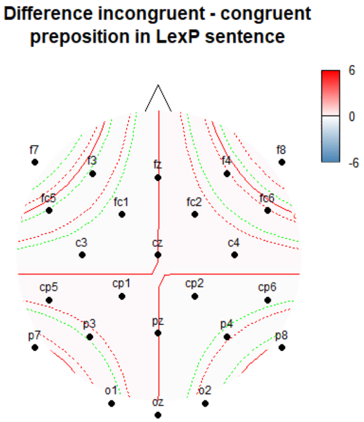


Figure 7.7. Topographical distribution of the amplitude difference between congruent and incongruent LexP sentences in the time window 450-550 ms following the onset of the preposition.

LexP sentences – Noun

The same method (i.e., with binary predictors) was used in this analysis as well. The model specifications were:

```
m1R <- bam(Pz ~ s(time.in.ms, k=20)
        + s(time.in.ms, by=Incongruent, k=20)
        + s(time.in.ms, id, by = congruency, bs='fs', m=1),
        data=subdat, discrete = TRUE, family='scat',
        AR.start = subdat$start.event, rho=m1rho)
```

As introduced in the Statistical analysis section, the dependent variable was the activity at a certain electrode (the first electrode to be analyzed was Pz). The model included congruency as a two-level dependent variable and the interaction between congruency and time. The Pz analysis yielded no main effect of congruency or interaction effect ($F(2.063, 5942.505)=0.587$; $p=0.466$) (Figure 7.8).

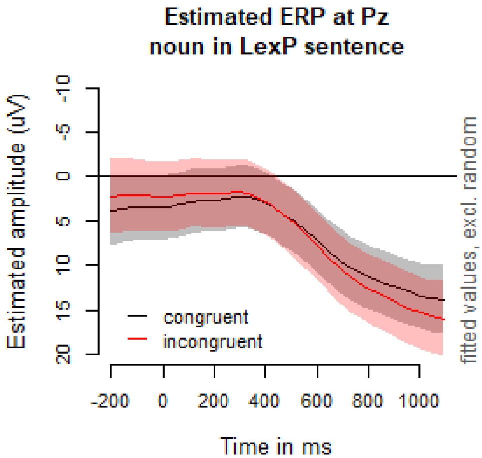
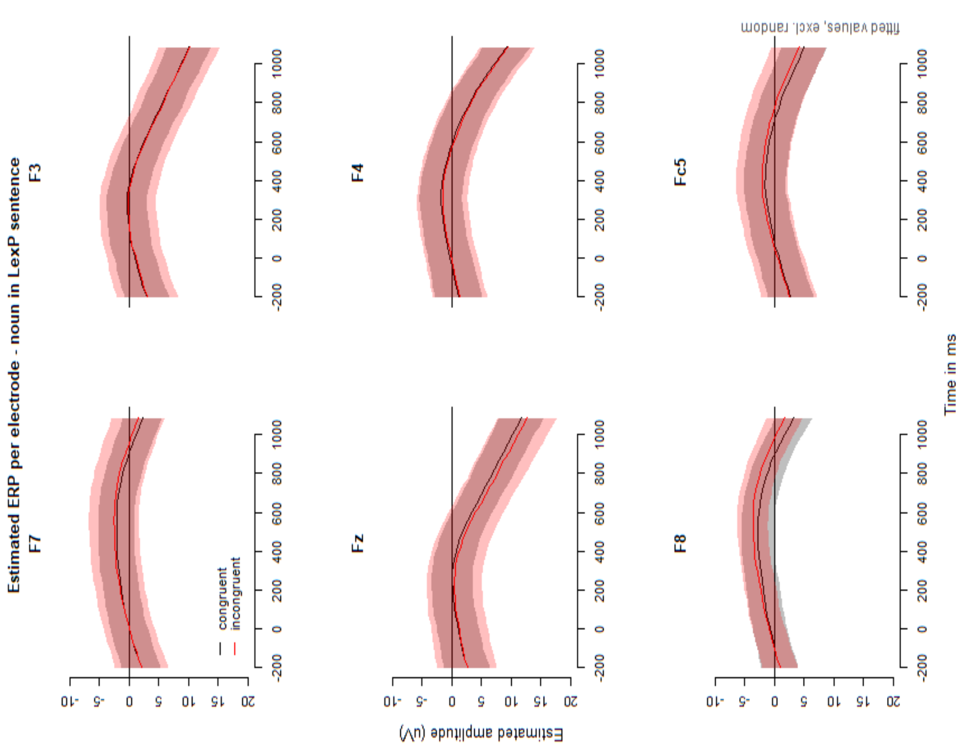
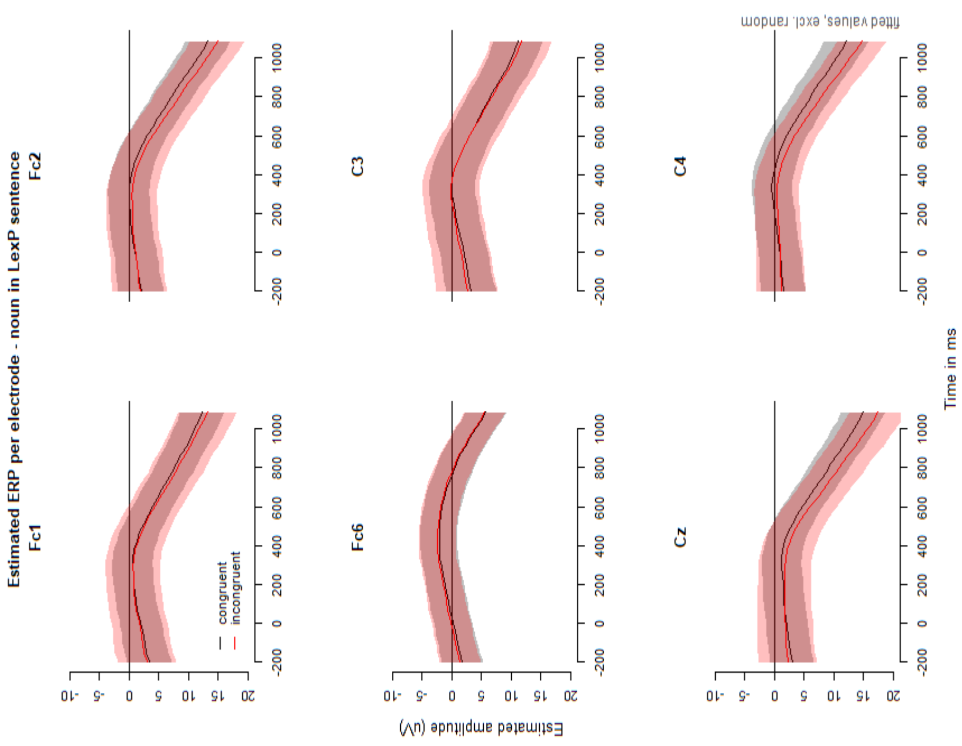


Figure 7.8. Activity at Pz electrode relative to a noun in LexP sentences. The black line models activity of the congruent trials and the red line models the activity for the incongruent trials. The shaded areas show confidence intervals.

Subsequently the rest of the electrodes were also analyzed, but no effects were found at any electrode for the nouns in LexP sentences. The modeled activity at all of the electrodes is given in Figure 7.9 below, while the grand average ERPs are given in Appendix C, Figure C-4.


Estimated ERP per electrode - noun in LexP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random


Estimated ERP per electrode - noun in LexP sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random

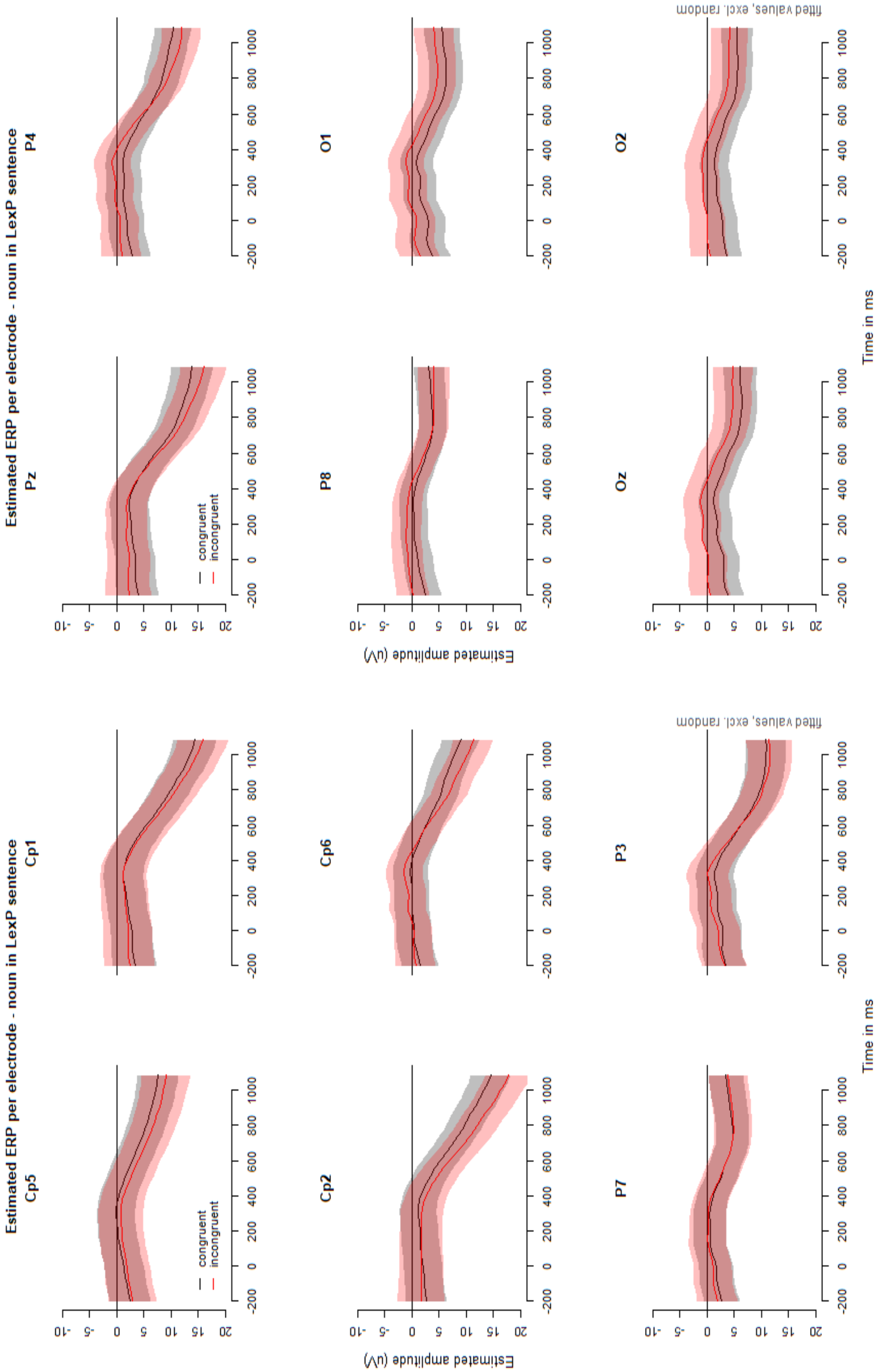


Figure 7.9. *Estimated ERP at all electrodes for the nouns in LexP sentences. There were no intervals where the effect was significant at any electrode.*

Next the difference in congruency in topography in the N400 window (450-550 ms after noun onset) was tested. There is a slight difference in this time window following the noun in LexP sentences ($F(1.657, 1088.096) = 3.237$, $p = 0.0395$) (Figure 7.10).

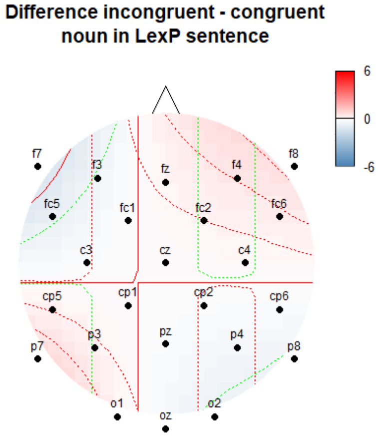


Figure 7.10. Topographical distribution of the amplitude difference between congruent and incongruent LexP sentences in the time window 450-550 ms following the onset of the noun.

7

SubP sentences – Prepositions

The same analysis was employed to assess the existence of a congruency effect relative to prepositions in SubP sentences. The model for Pz looked as follows:

```
m1R <- bam(Pz ~ s(time.in.ms, k=20)
        + s(time.in.ms, by=Incongruent, k=20)
        + s(time.in.ms, id, by = congruency, bs='fs', m=1),
        data=subdat, discrete = TRUE, family='scat',
        AR.start = subdat$start.event, rho=m1rho)
```

No main effect of Congruency ($F(3.01, 5953.424)=1.256$; $p=0.217$) on the preposition in SubP sentence at electrode Pz was observed (Figure 7.11). The analysis for the rest of the electrodes revealed no significant results either. The plots for the modeled activity for the prepositions in SubP sentences at all electrodes are given Figure 7.12 (the ERP activities at all electrodes are given in Appendix C, Figure C-5).

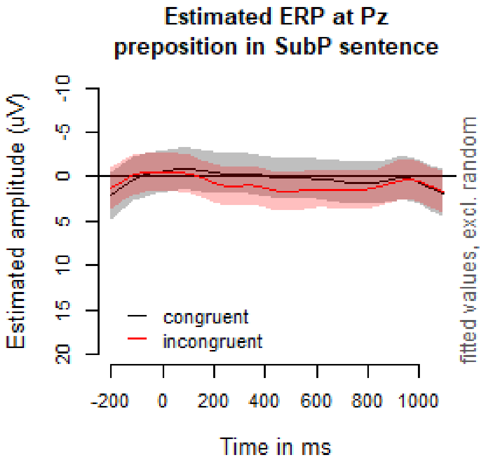
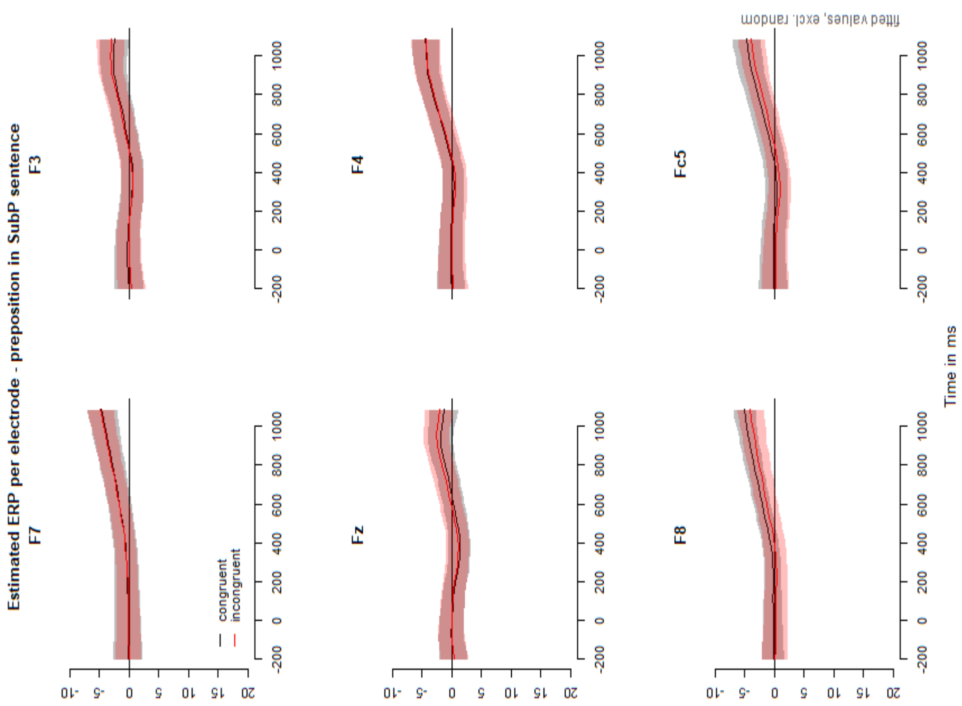
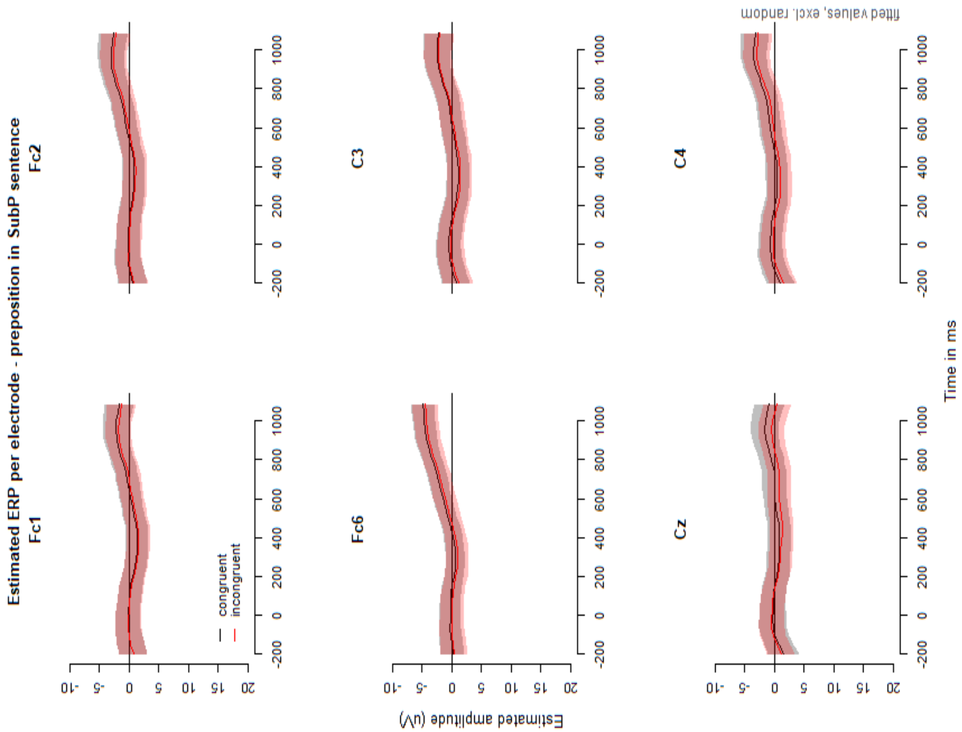


Figure 7.11. Activity at Pz electrode relative to a preposition in SubP sentences. The black line depicts activity of the congruent trials and the red line shows the activity for the incongruent trials.



Estimated ERP per electrode - preposition in SubP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random



Estimated ERP per electrode - preposition in SubP sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random

7

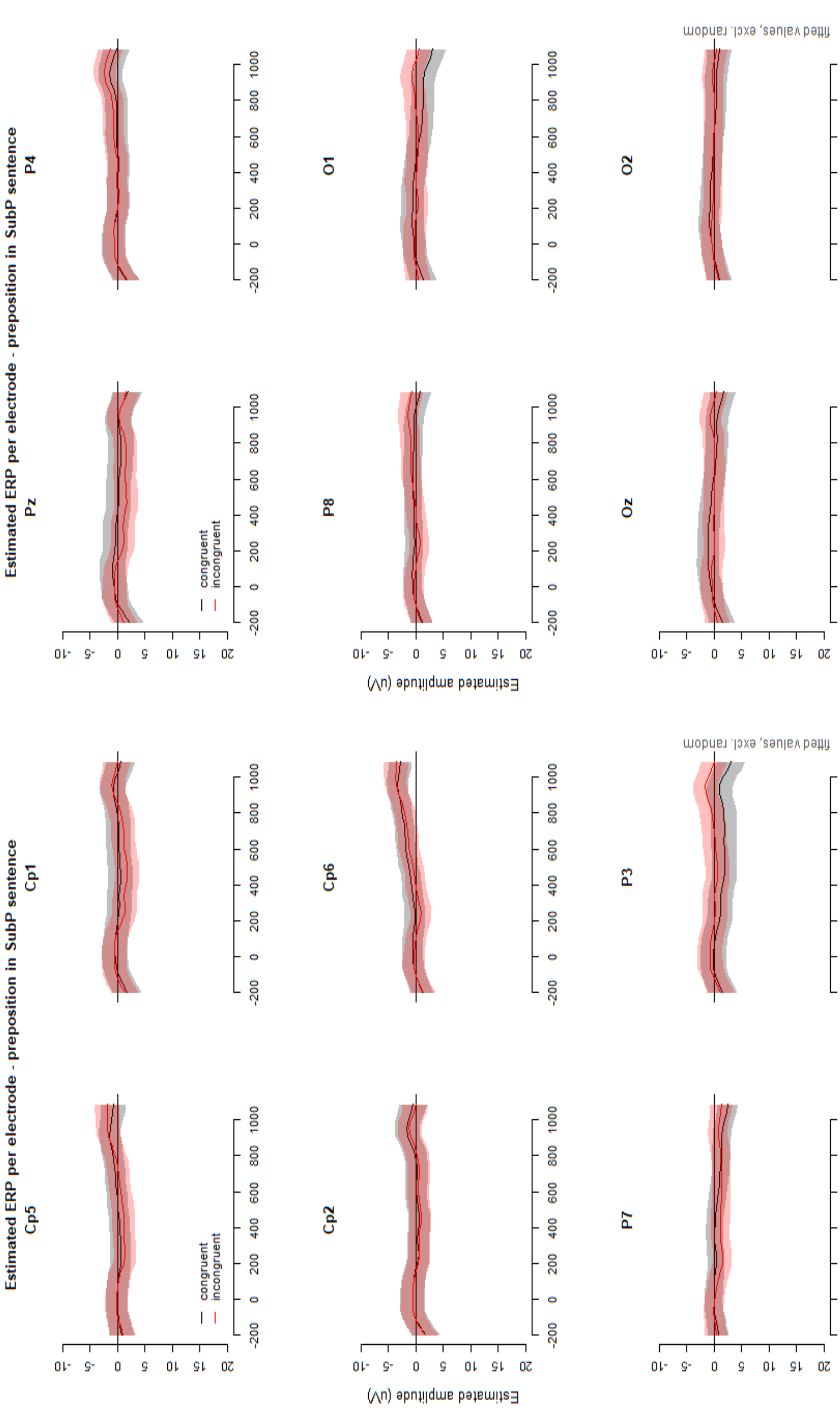


Figure 7.12. Estimated ERP at all electrodes for the prepositions in SubP sentences. There were no intervals where the effect was significant at any electrode.

Next the topography in the N400 window (450-550 ms after noun onset) was analyzed for prepositions in SubP sentences. There was a slight difference in this time window following the preposition in SubP sentences (F(1.000, 1096.927) = 4.023, p = 0.0451), with slightly more negative differences in a swath from left anterior to right posterior electrodes (Figure 7.13).

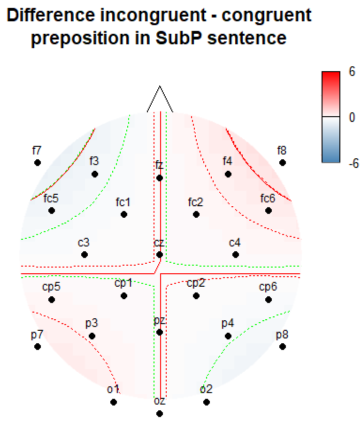


Figure 7.13. Topographical distribution of the amplitude difference between congruent and incongruent SubP sentences in the time window 450-550 ms following the onset of the preposition.

SubP sentences – Nouns

The same procedure and the model as in the previous analysis was employed for analyzing the activity relative the sentence-final noun onsets in SubP sentences.

The model was as follows:

```
m1R <- bam(Pz ~ s(time.in.ms, k=20)
      + s(time.in.ms, by=Incongruent, k=20)
      + s(time.in.ms, id, by = congruency, bs='fs', m=1),
      data=subdat, discrete = TRUE, family='scat',
      AR.start = subdat$start.event, rho=m1rho)
```

With the activity at a specific electrode as a dependent variable, while the model included congruency as a two-level variable and the interaction between congruency and time. No main effect of congruency was found for the nouns in SubP sentences at Pz (F(2.00, 5929.450)=0.383; p=0.682) (Figure 7.14).

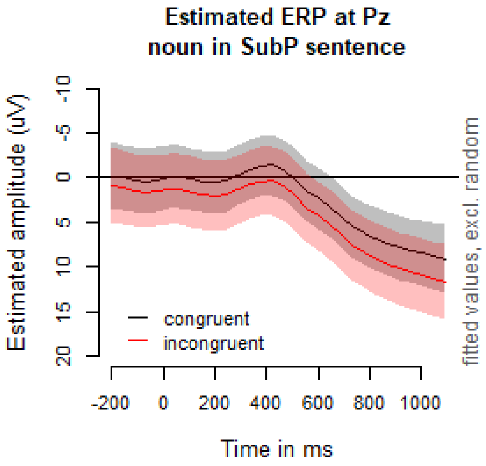
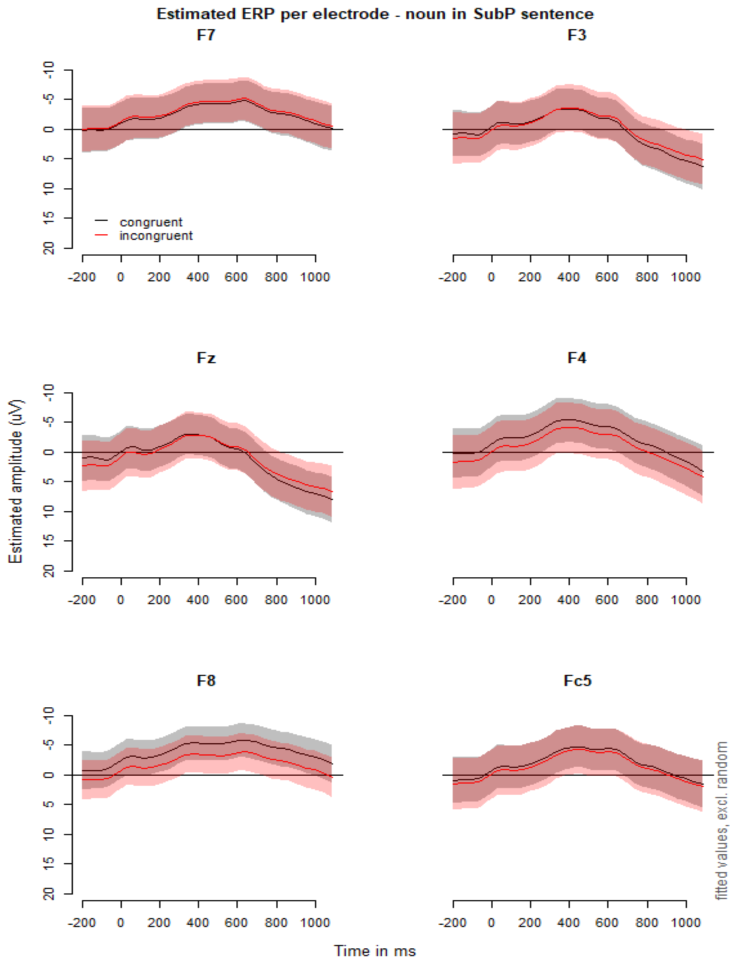
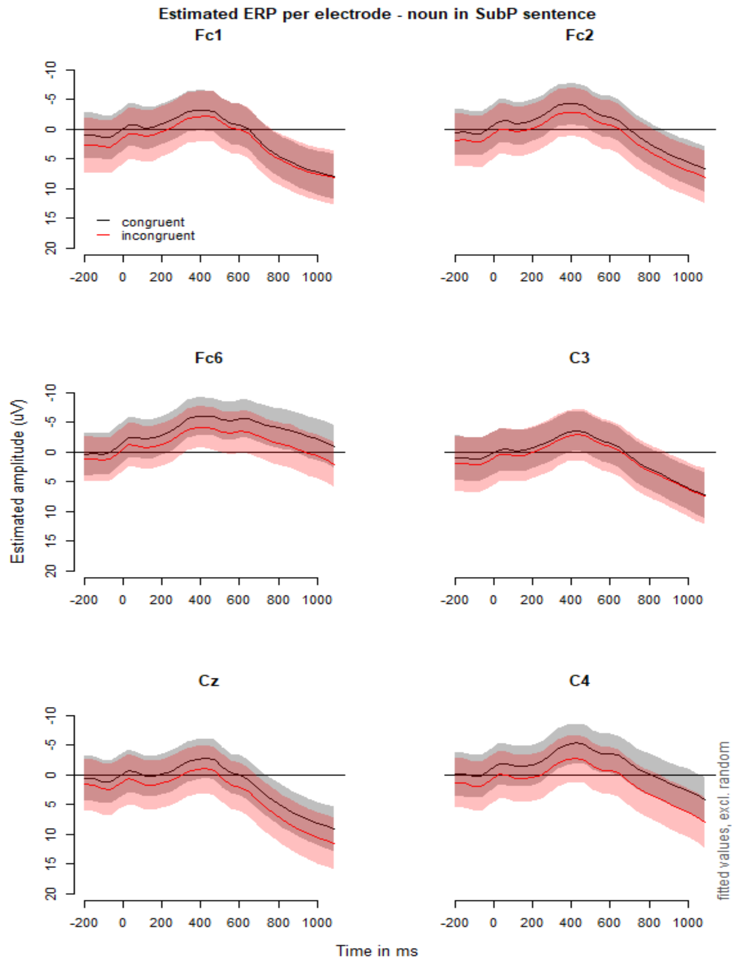


Figure 7.14. Activity at Pz electrode relative to a noun in SubP sentences. The black line depicts activity of the congruent trials and the red line shows the activity for the incongruent trials.

The analysis of the rest of the electrodes did not yield significant congruency effects at any electrode. The modeled activity at all electrodes is given in Figure 7.15, while the grand average ERP activities are given in Appendix C, Figure C-6.


Estimated ERP per electrode - noun in SubP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random


Estimated ERP per electrode - noun in SubP sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Estimated amplitude (uV)
Time in ms
fitted values, excl. random

7

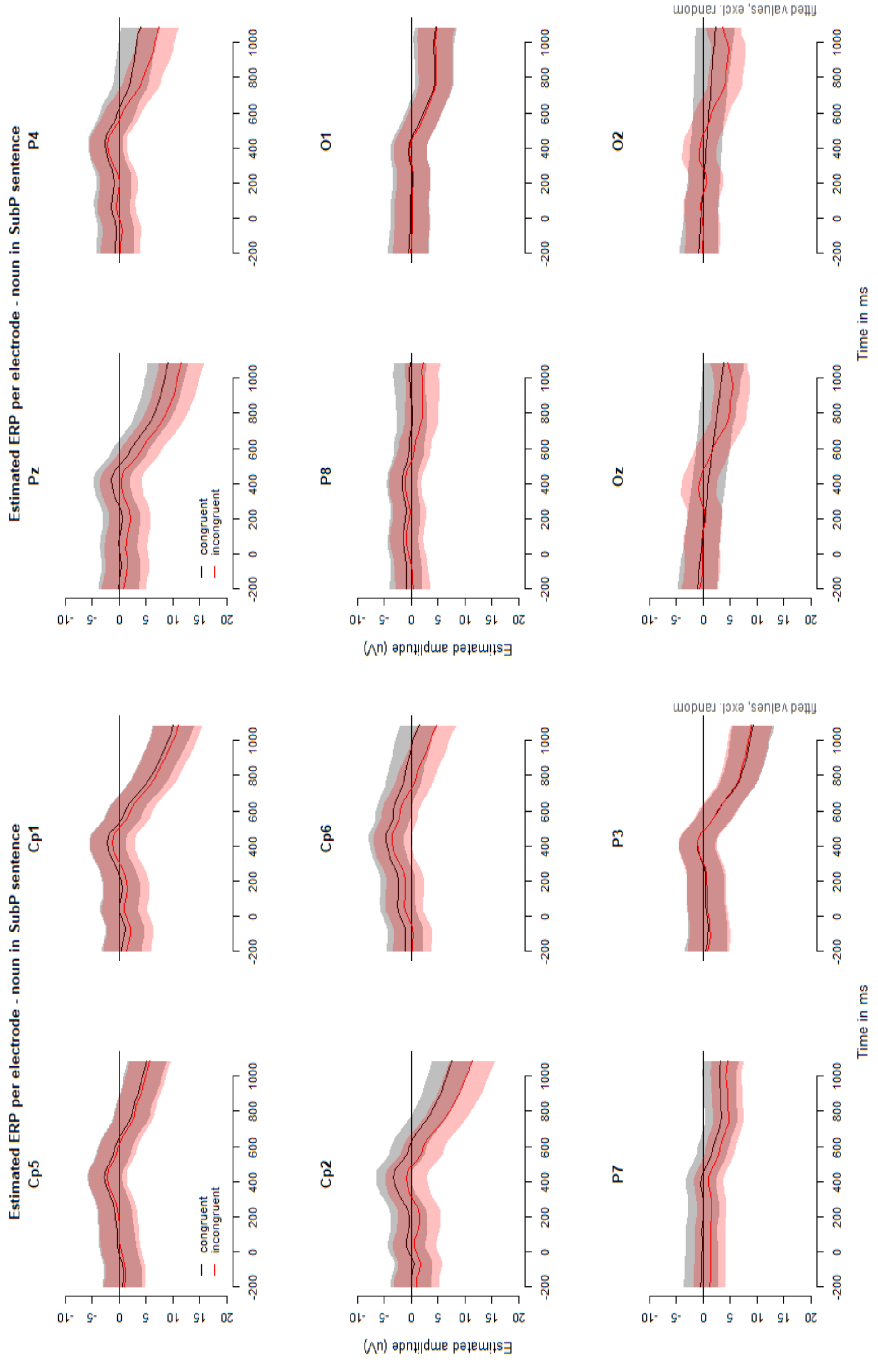


Figure 7.15. Estimated ERP at all electrodes for the nouns in SubP sentences. There were no intervals where the effect was significant at any electrode.

Next the topography in the N400 window (450-550 ms after noun onset) was analyzed. There was no difference in this time window following the noun in SubP sentences (F(1.000, 1089.358) = 0.98, p = 0.322) (Figure 7.16).

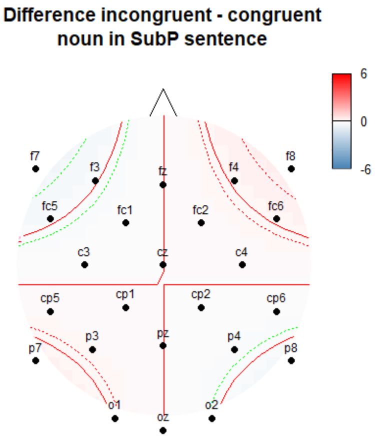


Figure 7.16. Topographical distribution of the amplitude difference between congruent and incongruent SubP sentences in the time window 450-550 ms following the onset of the noun.

7

Processing of LexP vs. SubP[15] – Prepositions

The processing *prepositions* in LexP and SubP sentences was compared. Because neither a main effect of congruency nor an interaction between sentence type and congruency was detected at any critical word in LexP and SubP sentences, congruent and incongruent trials were collapsed together for each type of sentence (LexP and SubP). First the activity relative to the prepositions was analyzed.

The following analysis was run to test whether children show distinct processing effects between *lexical* and *subcategorized prepositions* at the preposition.

The model was as follows:

```
m2R <- bam(Pz ~ s(time.in.ms, k=20)
      + s(time.in.ms, by=Lex, k=20)
      + s(time.in.ms, Event, bs='fs', m=1),
      data=subdat, discrete = TRUE, family='scat',
      AR.start = subdat$start.event, rho=m2rho)
```

The analysis revealed a main effect of sentence type (F(5.837, 11920.176)=2.34; p=0.022) at Pz around 200-400 ms and 950-1100 ms following the word onset (Figure

15 Important for the interpretation of the outcomes of the collapsed analysis is that the data was baseline corrected, as described in Chapter 4.

7.17). Activity relative to lexical prepositions in LexP sentences was more positively distributed than the activity relative to subcategorized prepositions.
No interaction between Sentence Type and Congruency was found.

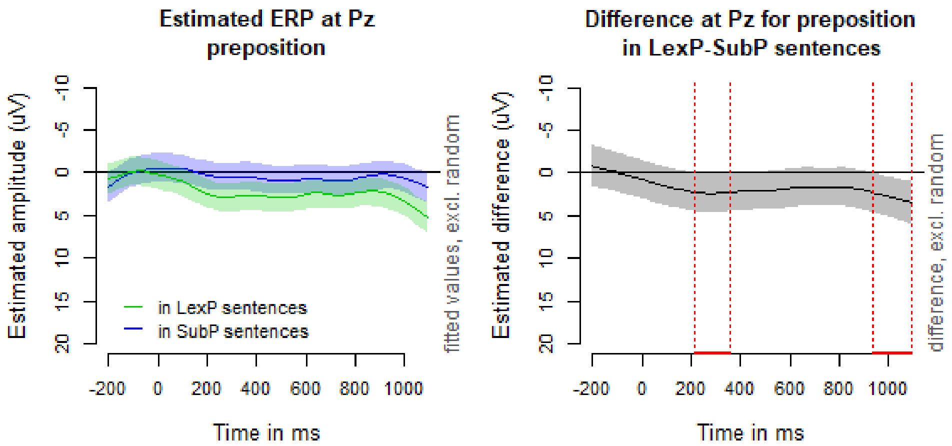
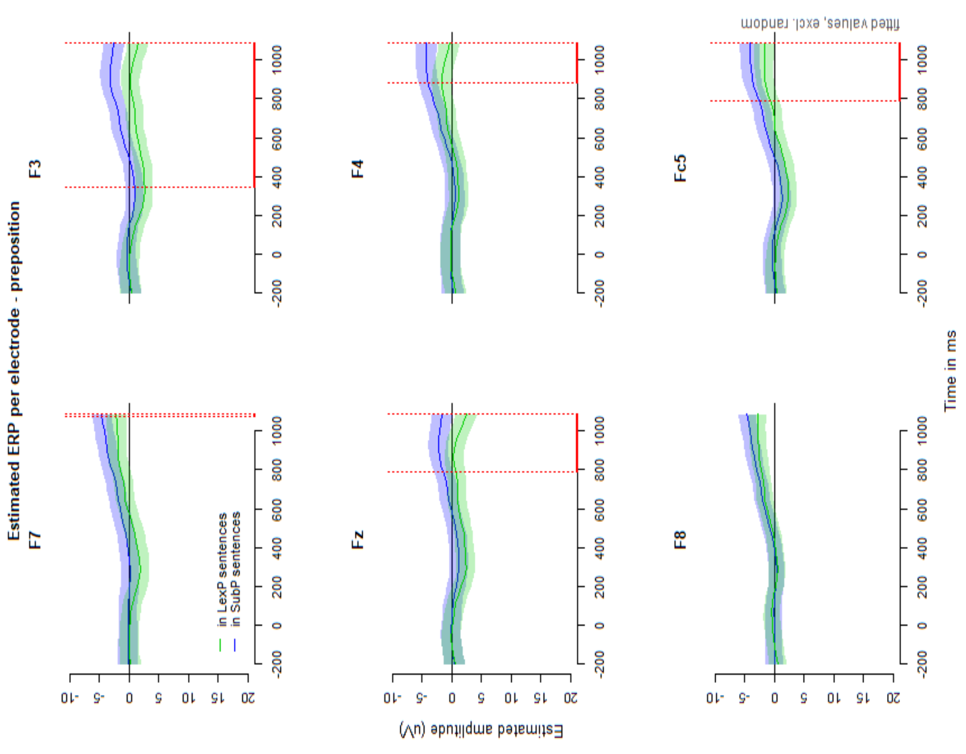
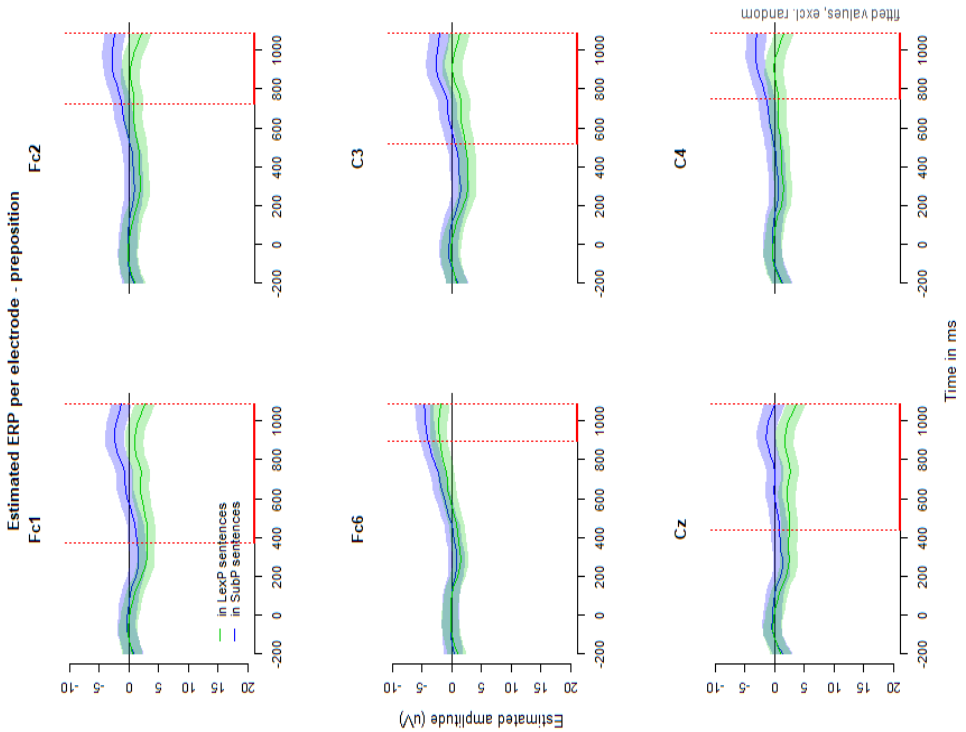


Figure 7.17. Panel A shows the activity at the prepositions in the congruent and incongruent trials from LexP and SubP sentences collapsed together. The green color shows activity for prepositions in LexP sentences, and the blue color depicts activity for prepositions in SubP sentences. Lightly shaded areas represent 95%-confidence intervals around the estimated activity. Panel B shows the difference waveform of lexical and subcategorized prepositions (with congruent and incongruent trials collapsed). The red horizontal lines show the timepoints in which the difference reaches significance. The gray shaded area represents the 95%-confidence interval around the estimated difference.

Subsequently, the model was run for the rest of the electrodes. Besides Pz, which was the first electrode to be analyzed, a main effect of sentence type was found for most of the electrodes. The modeled activity at all electrodes is given in Figure 7.18 (the grand averages are given in Appendix C, Figure C-7). Similarly to the activity at Pz, incongruent lexical prepositions were processed significantly differently from incongruent subcategorized prepositions. As we can see from the figure 7.18, the waves for SubP trails (blue line) are negatively distributed relative to the waves for LexP trials (green line).



Estimated ERP per electrode - preposition
F7
F3
Fz
F4
F8
Fc5
in LexP sentences
in SubP sentences
Estimated amplitude (uV)
Time in ms
fitted values, excl. random



Estimated ERP per electrode - preposition
Fc1
Fc2
Fc6
C3
Cz
C4
in LexP sentences
in SubP sentences
Estimated amplitude (uV)
Time in ms
fitted values, excl. random

7

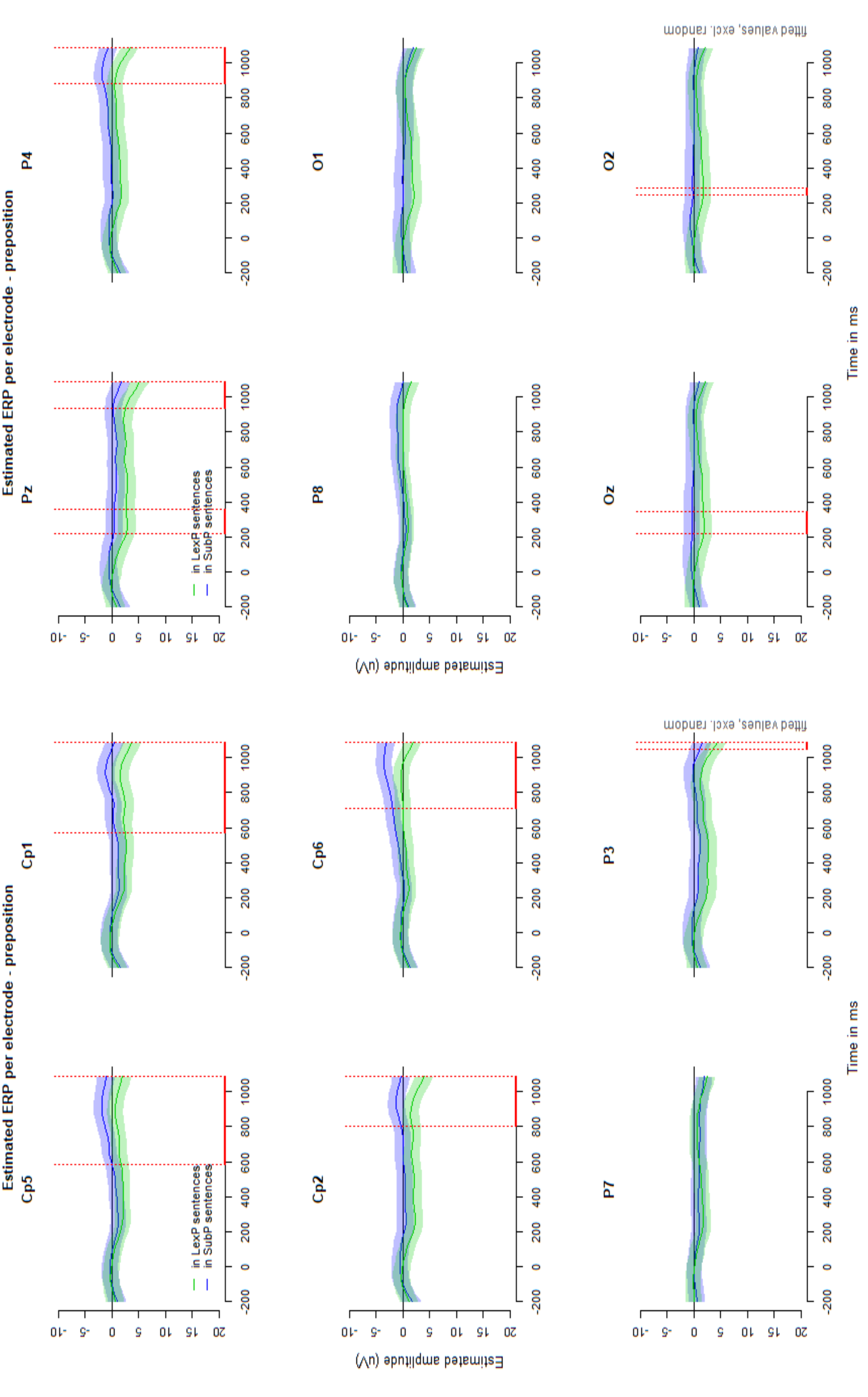


Figure 7.18. The modeled activity at all electrode sites relative to prepositions in LexP vs. SubP sentences. Congruent and incongruent sentences are collapsed per sentence type. The green color shows the activity for the LexP sentences and the blue color the activity for SubP sentences.

As it can be seen from Figure 7.18, comparison of LexP and SubP sentences in the time period following the prepositions was significant at two time windows. These were, roughly between 200 and 400 ms (at electrodes F3,Fc1, Pz, Oz, O2) and roughly between 950 and 1100ms (at F7, F3, Fz, F4, Fc5, Fc1, Fc2, Fc6, C3, Cz, C4, Cp5, Cp1, Cp2, Cp6, P3, Pz, P4) following the preposition onset. Therefore, topographical difference in congruency was tested in these two time windows. However, no significant difference in topographical distribution was detected either in the 200-400 ms window ($F(5.151, 2240.574) = 1.25$; $p=0.260$) or in the 950-1100 ms window ($F(4.763, 2239.521)=1.27$; $p=0.276$).

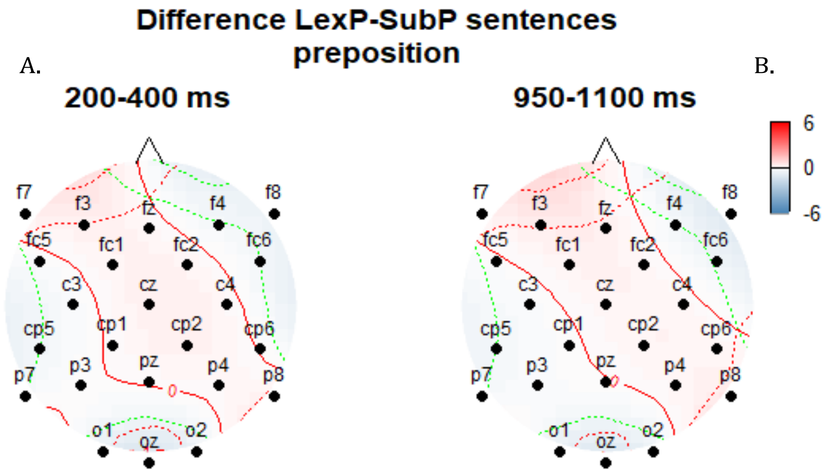


Figure 7.19. Topographical distribution of the amplitude difference between LexP and SubP sentences (congruent and incongruent collapsed together) in the time window 200-400 ms (panel A) and 950-1100 ms (panel B) following the onset of the preposition.

Processing of LexP vs. SubP – Nouns

The processing of sentence final *nouns* in LexP and SubP sentences was compared. Congruent and incongruent trials were collapsed together for each type of sentence (LexP and SubP). The aim of the analysis was to examine whether children show any processing effects for the nouns following the lexical and subcategorized prepositions.

The model was as follows:

```
m2R <- bam(Pz ~ s(time.in.ms, k=20)
        + s(time.in.ms, by=Lex, k=20)
        + s(time.in.ms, Event, bs='fs', m=1),
```

```
data=subdat, discrete = TRUE, family='scat',
AR.start = subdat$start.event, rho=m2rho)
```

The analysis revealed a main effect of Sentence Type (F(4.654, 11856.441)=2.61; p=0.020) at Pz around 600-1000 ms after noun onset. In this time window (600-1000 ms), the waveform for LexP sentences was more positively distributed than the waveform for SubP sentences. This effect is visualized for Pz in Figure 7.20 below.

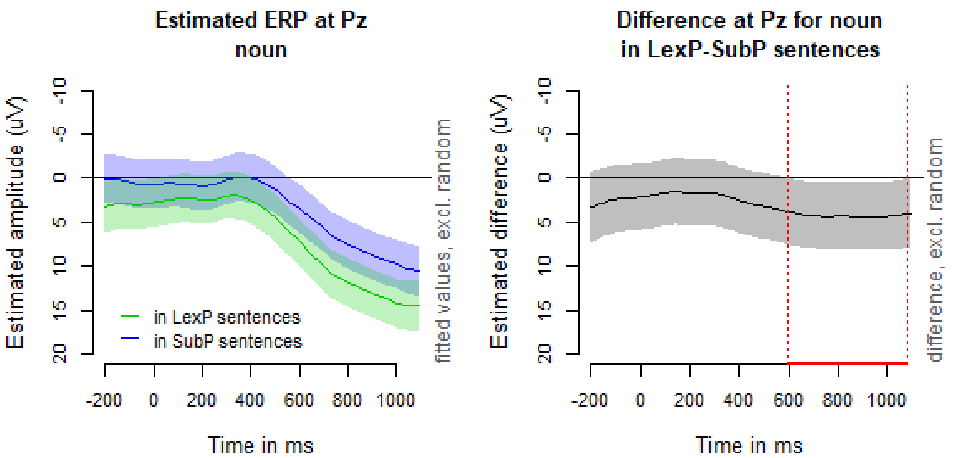
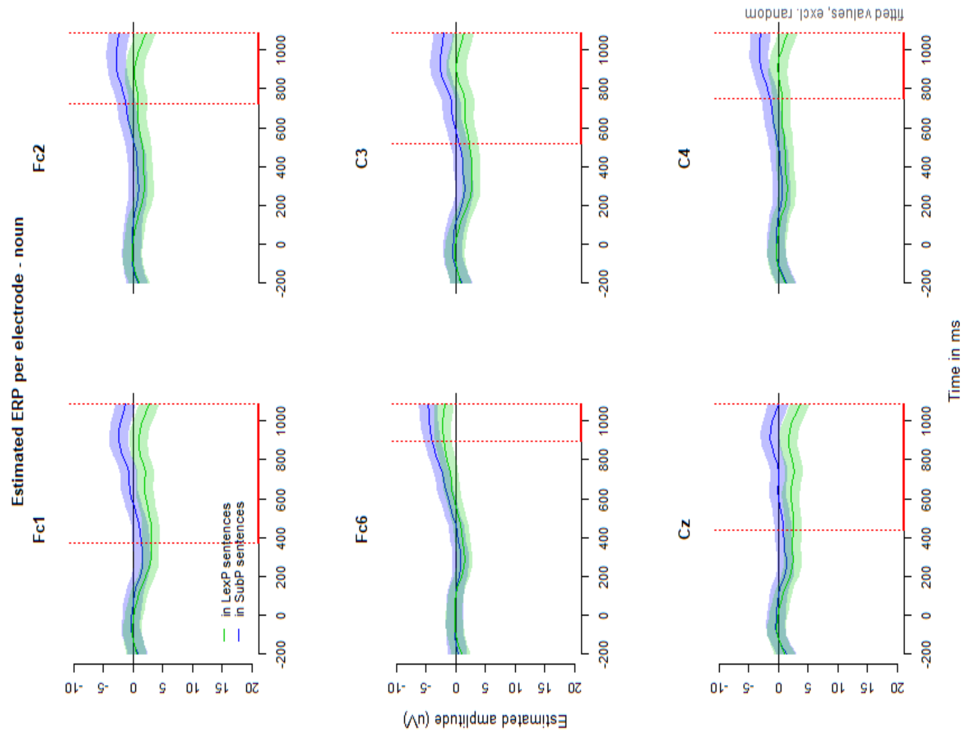
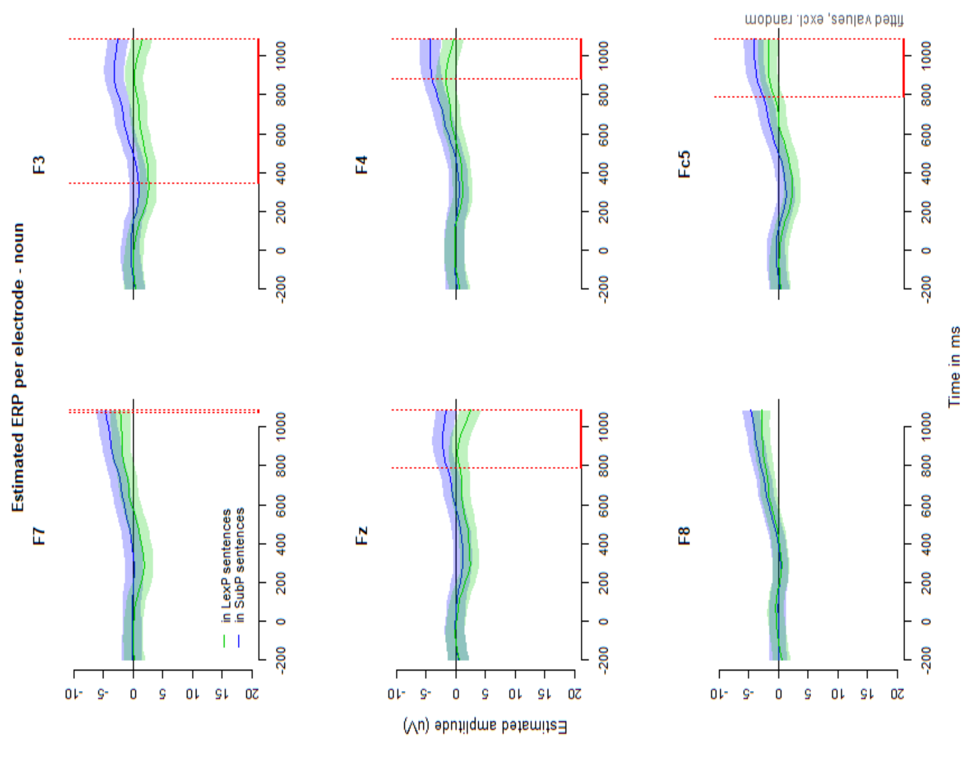


Figure 7.20. Panel A shows the modeled activity at nouns in LexP and SubP sentences with congruent and incongruent sentences collapsed together. The green line shows the activity for nouns in LexP sentences, and the blue line depicts activity of the nouns in SubP sentences. Lightly shaded areas represent 95%-confidence intervals around the estimated activity. Panel B shows the difference waveform of nouns in LexP vs. SubP sentences(with congruent and incongruent trials collapsed). The red horizontal lines show the timepoints in which the difference is statistically significant. The gray shaded area represents the 95%-confidence interval around the estimated difference.

As in the previous analysis, the model was then run for the rest of the electrodes. The effect was significant at most of the electrodes as shown with red dotted lines in the Figure 7. 21 below (the grand averages for the nouns in LexP vs. SubP are given in Appendix C, Figure C-8). That is, nouns in the context of incongruent lexical prepositions were processed significantly differently from the nouns in the context of incongruent subcategorized prepositions. As we can see from the figure 7.21, the waves for SubP trails (blue line) are negatively distributed relative to the waves for LexP trials (green line).



Estimated ERP per electrode - noun
Fc1
Fc2
Fc6
C3
Cz
C4
in LexP sentences
in SubP sentences
Estimated amplitude (uV)
Time in ms
fitted values, excl. random



Estimated ERP per electrode - noun
F7
F3
Fz
F4
F8
Fc5
in LexP sentences
in SubP sentences
Estimated amplitude (uV)
Time in ms
fitted values, excl. random

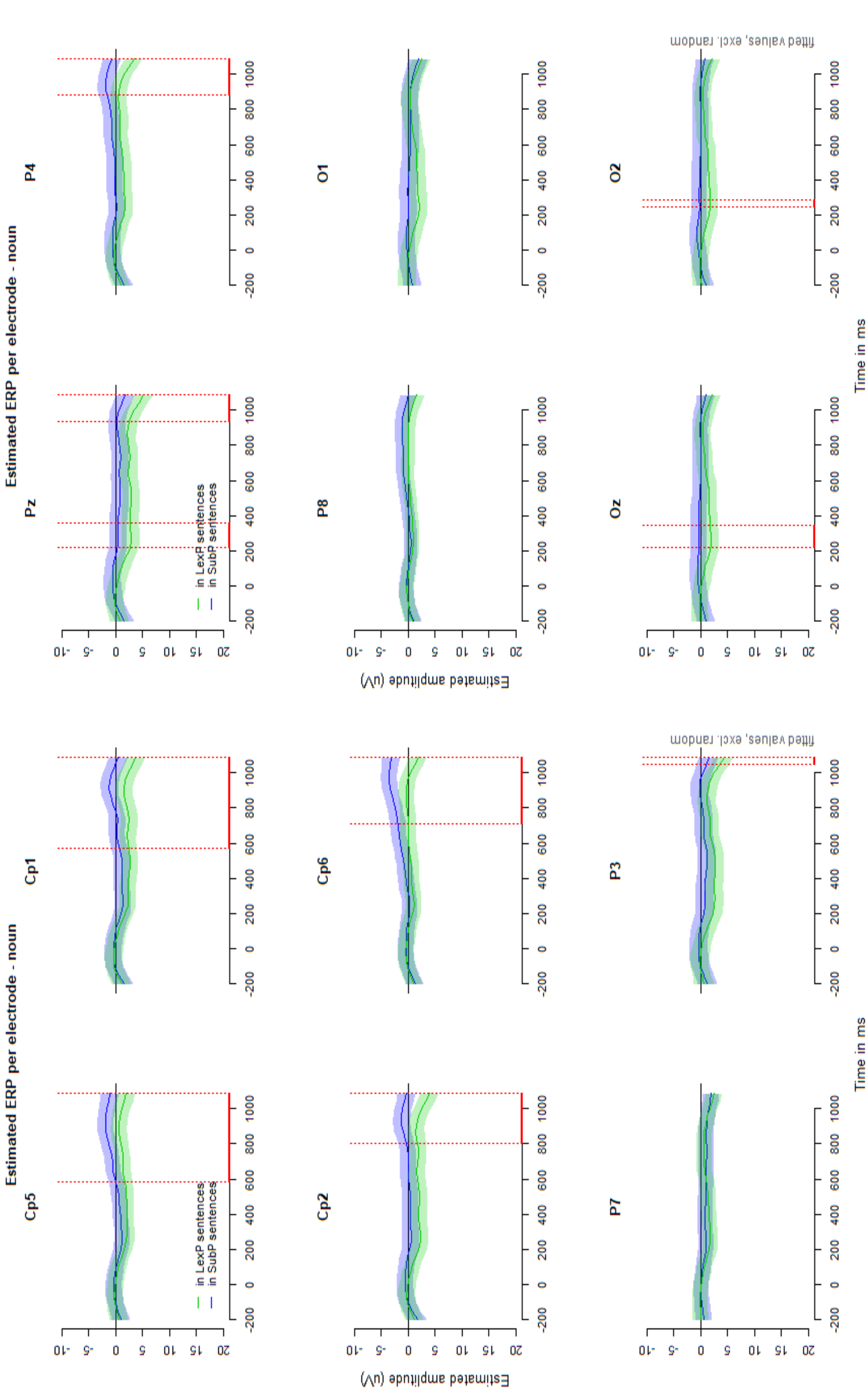


Figure 7.21. *The modeled activity at all electrode sites relative to nouns in LexP vs. SubP sentences. Congruent and incongruent sentences are collapsed per sentence type. The green color shows the activity for the LexP sentences and the blue color the activity for SubP sentences.*

Next the difference in topography in a window 600-1000 ms after noun onset was analyzed. However, no significant difference in topographical distribution is detected (F(6.717, 2233.164)=1.38; p=0.209).

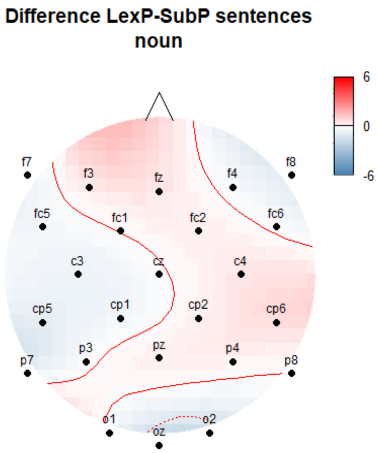


Figure 7.22. Topographical distribution of the amplitude difference between LexP and SubP sentences (congruent and incongruent collapsed together) in the time window 600-1000 ms following the onset of the noun.

7

7.5. Discussion

In this study, the processing of prepositions in lexical and functional use by children aged 6- to 13 years was examined. ERP methodology was applied to examine how children process each type of preposition in incongruent sentence contexts (as opposed to congruent). In addition, a control set of sentences not containing any prepositions was employed for the elicitation of a "classical" N400. Since it is well-established that children show an N400 effect as the correlate of semantic incongruency, these control sentences served to validate the paradigm and to help interpret the effects found as a result of the processing of prepositions by children, given that no reported studies examine the processing of prepositions in children (of any age) using the ERP methodology.

In what follows, I will present the discussion of the results starting from the control sentences. Subsequently, the discussion of the results concerning LexP and SubP sentences will be presented.

Processing of control sentences

Incongruent control sentences elicited an N400 effect similarly to previous studies reporting an N400 in association to semantic incongruency in children (Hahne, et al. 2004; Friederici, 2006). The effect was found roughly between 400 and 650 ms following the onset of the critical noun and with a maximum in the posterior region of the brain. It should be mentioned though, that the effect was only significant at a few electrodes, suggesting that the effect is not very robust. The strength of this effect could have been influenced by the age variation (6- to 13years) in the child sample participating in this experiment. Recall from Chapter 3 on language-related ERPs in children that the characteristics of a component (e.g., an N400) undergo changes with age in terms of latency, amplitude and distribution and get stabilized from puberty (Holcomb et al., 1992). Therefore, a relatively wide age-range of the children participating in this study could have affected the statistical power resulting in the effect being less robust than it is in more homogeneous groups of participants.

In summary, although the N400 effect was relatively modest, this outcome shows that the children did detect semantic incongruency in the control sentences, which was reflected in their brain activity. This establishes the basic validity of the experimental paradigm and provides a basis for the interpretation of effects found as a result of the processing of prepositions.

Experimental sentences

Processing of two critical words, a preposition and a noun, was analyzed for potential ERP effects per sentence type, that is, for LexP and SubP separately. Statistical analysis revealed no congruency effects either in LexP or SubP sentences. These results are in clear contrast with the ERP results from the adult study presented in Chapter 5. As we saw there, the incongruent lexical prepositions elicited an N400 effect, whereas incongruent subcategorized prepositions elicited a P600. Furthermore, the processing of sentence-final nouns following each type of preposition displayed P600 effects. In addition to the positive effect, nouns in the context of incongruent lexical prepositions elicited an N400 effect. None of these effects were revealed by the analysis of the data from children. This outcome is somewhat puzzling taking into account that children's behavioral responses (sentences judgement task) were 87.9% accurate on LexP and 86.4% on SubP sentences. Although this level of accuracy is not very high (recall from Chapter 5 that adults reached 92.3% on congruent and 97.3% on incongruent sentences for LexP sentences and 93.8% congruent and 96.1% on incongruent SubP sentences), they still show that children are able to detect congruency to a certain degree offline.

The fact that no congruency effects were found suggests that children did not process incongruent prepositions and the nouns following them differently from the prepositions and nouns in the congruent condition. This outcome is also in contrast to the N400 effect elicited by semantically incongruent nouns in the control sentences, which provided evidence that children in this experiment are sensitive to semantic incongruency.

Several explanations can be proposed as to why no congruency effects were found in any of the experimental conditions. As I have presented in the methodology chapter of this thesis, prepositions in incongruent LexP and SubP sentences were used as dispreferred rather than proper violations in the context (for details of the sentence design see Chapter 4). Therefore, one could assume that this dispreferred usage of prepositions, as opposed to violations, prevented the occurrence of the processing effects. Importantly, the sentence-final nouns in incongruent trials in the control sentences were outright semantic violations in the preceding context. However, as has been presented in Chapter 5, an N400 effect for the processing of incongruent lexical prepositions and a P600 for the incongruent subcategorized prepositions were elicited for this dispreferred usage of prepositions with adult participants (recall that the stimuli used in both studies were identical), demonstrating that the adult brain is able to detect such dispreferred uses of prepositions. But what about the developing brain? An explanation for the discrepancy between the processing effect of adults and children can be that the developing brain could be less sensitive to such dispreference (as opposed to clear semantic violations) because of less experience with language (processing). Besides, as mentioned several times throughout this thesis, prepositions are quite special in that they are a small set of short words which are polysemous, can have distinct linguistic functions and can be homonymous with other grammatical categories e.g., particles. As a result, when there are so many possibilities of interpretation, children may not be able to attach function and meaning (if there is any) to prepositions as quickly as adults do. Children are generally believed to have slower processing speed than adults (Kail, 1991). Therefore, one is prompted to think that possibly the effect to the incongruent prepositions occurred but with a delayed latency. In the behavioral result section of this study, we saw that children were able to judge the accuracy of the sentences with congruent and incongruent prepositions mostly correctly (87.9% (SD 7.1) on LexP and 86.4% (SD 8.7) on SubP. This discrepancy between online and offline outcomes could suggest that some ERP processing effects did occur but beyond the epochs selected for analysis (extension of these epochs would have led to potential interference from preparation of the motor response, i.e., a button press).

As for the processing of the nouns following congruent and incongruent lexical and subcategorized prepositions, from Chapter 4 we know that the fit of the sentence-final nouns in the preceding context is determined by the preposition preceding it. Thus, the processing of a noun as congruent or incongruent largely depends on the appropriate processing of the prepositions both in LexP and SubP sentences. The fact that no congruency effects were found already at the preposition probably explains the lack of the effect at the noun. For detecting the incongruent nouns children had to process prepositions first. As we have seen, no effects were elicited relative to the incongruent prepositions (both lexical and subcategorized) and the possible explanations for this outcome are delayed processing and/or lack of statistical power because of large age variation in the child sample. Both of these aspects would probably also have reduced or eliminated ERP effects on the noun.

From the behavioral results of the experimental and control sentences, we see that children were able to judge the accuracy of experimental sentences better (the accuracy was 87.9% on LexP and 86.4% on SubP) than of the control sentences (72.6% accurate). Still the ERP effect (namely, the N400) was only found for the processing of incongruent *control* sentences. In other words, if children were able to determine accuracy of the experimental sentences well, why do we not see congruency effects expressed in ERPs? To explain this seeming contradiction, we should bear in mind that behavioral and online (in this case ERP) methods measure crucially different variables. Offline/behavioral techniques measure the end state of the processing, i.e., conscious processing and decision-making, whereas online techniques (ERPs) show us the processing of information, of language in this case, as it unfolds in time without clear conscious engagement. Thus, these behavioral and ERP outcomes can suggest that children in this experiment are able to detect inaccurate sentences having consciously processed them, but they seem not be able to do similarly online, i.e., at the stage of unconscious processing when the sentences are still unfolding in time.

In sum, finding no processing effects can be explained by the properties of prepositions shared between lexical and subcategorized prepositions such as low perceptual salience, polysemy and several functions of prepositional forms. Given the slow processing characteristics of children (Kail, 1991), these properties of prepositions could have considerably delayed the processing effects of incongruities in sentences, if there were any.

Processing of LexP vs. SubP sentences

In the final analysis, the processing of prepositions and nouns in LexP sentences were compared to the processing of prepositions and nouns in SubP sentences. For this analysis congruent and incongruent trials were collapsed together. These analyses were run to verify whether children show any difference in the processing of LexP and SubP sentences. Although this analysis diverges from the traditional method of ERP analysis in neurolinguistic research, in which often incongruent trials are compared to congruent ones, collapsing them together is not unreasonable taking into account that no differences were found between congruent and incongruent trials (see above). The advantage of these analyses is that it informs us about the general processing of sentences with two types of prepositions. In traditional ERP analysis, we talk about the polarity and amplitude of ERP effects. In this case, however, these parameters are not relevant and obviously, one cannot talk about specific ERP effects either, as none of the trials can be considered as standard or congruent against which the other is compared. What this analysis can show us though is whether the brain processes trials with linguistically distinct prepositions differently. The analyses revealed a significant difference between the waveforms for LexP and SubP trials both at the preposition and at the noun. For the noun the processing difference was quite widespread in topography and occurred from 400 ms onwards. This outcome tentatively suggests that the developing brain is not completely indifferent to the processing of LexP and SubP trials both at the preposition and at the noun. The distinct linguistic properties of lexical and subcategorized prepositions can have resulted in the processing difference found at the point of prepositions. As for the processing difference found at the nouns, one can assume that the nouns following lexical prepositions are processed directly in relation to the lexical prepositions, whereas the nouns following subcategorized prepositions are processed in the context of the verb + preposition combination (as opposed to only preposition). We saw in the results section of this chapter that the waves for the SubP trials were more positively distributed than those of LexP trials, which could suggest that children show the reversed processing pattern from adults at the point of preposition. Recall from Chapter 5 that I found negative effects associated to incongruent lexical prepositions and positive effect for the processing of incongruent subcategorized prepositions. However, one should be wary of such a conclusion as the analysis applied in each case (adult study vs. child study) was completely different as discussed in section 7.3. As argued earlier, this analysis of comparing the processing of LexP and SubP trials with the congruent and incongruent sentences collapsed together diverges from the traditional ERP analysis. Therefore, one cannot make conclusions based on this analysis in terms of traditional ERP classification of the effects.

In sum, the aim of this ERP study with TD children was to find out whether children similarly to adults show the processing distinction between prepositions n lexical and functional use. Although a clear processing difference similar to adults (Chapter 5), who displayed dedicated ERP components for the processing of violations of lexical and subcategorized prepositions was not found in children, in the final analysis of the data, when the processing of the LexP sentences was compared to the processing of SubP sentences (congruent and incongruent collapsed together) there was a difference between the processing of prepositions in lexical vs. functional use (and nouns in their context). This result tentatively suggests that the developing brain does in fact make a distinction between the two uses of prepositions.

Chapter 8.

Comprehension and production of prepositions in German-speaking children with cochlear implants [16]

16 Parts of this chapter are based on: Chanturidze, M., Carroll, R., Finke, M., & Ruigendjik, E. (in preparation). Comprehension and Production of Prepositions in German-speaking Cochlear Implanted Children.

Abstract

The acquisition of prepositions was tested in a group of children with CIs. Having low perceptual salience, prepositions can be especially difficult for children with CIs to perceive and acquire because the speech signal provided to them by CIs is qualitatively degraded. As prepositions are very frequent and have different linguistic uses (e.g., lexical like nouns or verbs, and functional like determiners), it is crucial for successful language acquisition that they are properly mastered.

Comprehension and production of prepositions in lexical and functional usage were tested in eight German-speaking children with CIs (*M* = 10;07; *SD* 2;2 years). A group of typically developing children (*M* = 9;4 *SD* = 1;6 years) served as control. A *sentence acceptability judgment task* was used to test the comprehension of prepositions. For studying the production of prepositions, *contrastive elicitation tasks* with pictures were employed.

The results showed that children with CIs lag behind their age-matched peers on the comprehension and production of both types of prepositions. Age at implantation and hearing age explained individual variation in the performance on prepositions. Furthermore, visual working memory, but not verbal working memory, served as a predictor for the comprehension of prepositions.

The outcomes of the study demonstrate that children with CIs are delayed in the mastery of prepositions; however, with longer hearing experience they catch up with TD children. Furthermore, the earlier children are implanted, the better they can master prepositions.

8.1. Short introduction and research questions

To acquire language, children use auditory speech information from the ambient language. Successful language acquisition presupposes proper auditory functioning (Mueller, Friederici & Männel, 2012). Studies directed at examining language skills in children with CIs are critical for improving the quality of their everyday communication as auditory deprivation before implantation and degraded spectral signal delivered to the brain by CIs affect their language perception and as a result how these children master language (Drennan & Rubinstein 2008; Schouwenaars et al., 2019). As discussed in more detail in in Chapter 2, section 2.3 of this dissertation, the existing literature on language skills in children with CIs suggests that the acquisition of prepositions can be problematic in this population (e.g., Lichtenstein, 1998; Szagun, 2000; Le Normand et al.,2003). Besides, clinicians have named prepositions one of the problematic word classes for these children. Although prepositions can be potentially problematic for children with CIs to acquire, and although clinicians have noticed that these words are often compromised in the language of these children, there are no published studies investigating prepositions so far. The topic of this chapter is the comprehension and production of prepositions in lexical and functional use in children with CIs.

The main question posed in this study is whether children with CIs comprehend and produce prepositions on an age-appropriate level, i.e., equal to TD peers. Previous research shows that children with CIs experience more difficulties with words carrying functional features than meaningful words (Szagun, 2004). Does this finding mean that children with CIs will do better on lexical than on more functional subcategorized prepositions? Furthermore, if children with CIs indeed experience problems with prepositions, does the deprivation of auditory stimuli cause a permanent harmful effect on the acquisition of prepositions or does the mastery of prepositions improve with age and, therefore, is delayed but normally developing otherwise? Research on the language development of children with CIs has shown that hearing age (i.e., the chronological age minus the age at implantation) and working memory play an important role in language performance (Harris et al., 2013; Kronenberger et al., 2011; Pisoni et al., 2011; Kral et al., 2016). Therefore, the influence of these two aspects, namely the hearing age and working memory, on the mastery of prepositions was also examined in the study reported in this chapter. To obtain a comprehensive view of the working memory capacities in children with CIs, both verbal and visual working memory measures were used.

Regarding the comprehension and production of prepositions, it was expected that children with CIs have not acquired prepositions equally to their TD peers. Taking into account the linguistic properties of prepositions, such as being short in length and typically unstressed, which make certain lexical elements potentially more difficult to acquire for children with CIs (Szagun, 2004; Hammer et al., 2014), the acquisition of prepositions was expected to be impeded. Based on the existing evidence that linguistic elements which lack semantic meaning (i.e., functional categories) are difficult for children with CIs (Le Normand et al., 2003; Szagun, 2000 & 2004), it was expected that children with CIs would do better on lexical, i.e., meaningful prepositions than on virtually meaningless subcategorized prepositions. If the performance of children with CIs on prepositions improves with age, this would suggest a delayed development of this category. On the other hand, if one or both types of prepositions (lexical and subcategorized) remain problematic for both younger and older children, this would suggest impairment (or atypical development) of this category. Furthermore, an association between the linguistic outcomes and hearing age was expected, that is, the longer children have been implanted the better their performance on prepositions would be. In addition, based on previous findings, working memory capacity was expected to affect the performance on prepositions.

8.2. Materials and Methods

The comprehension experiment involving a *sentence acceptability judgement task* (see section 4.1, Chapter 4 for details about the sentence design used) was administered first, followed by the production experiment involving *contrastive elicitation tasks I* and *II* (see section 4.2, Chapter 4 for a detailed description of the materials used). Subsequently, children performed the working memory tasks, namely, one-syllable word span, digit forward span, Corsi block test and matrix span (Arbeitsgedächtnistestbatterie für Kinder im Alter von 5-12 Jahren (AGTB 5- 12)).

8.2.1. Participants

Eight[17] prelingually deaf children aged between 6;1 and 11;11 years participated in the study (3 female, *M* = 10;07; *SD* = 2;2 years). Seven children had bilateral CIs while one child used one CI and one hearing aid. All these children were implanted at the age of 2;9 years or younger. They were monolingual speakers of German and otherwise typically developing (for individual profiles of children with CIs please see Table 8.1).

17 Although the aim was to recruit more children with CIs for the experiments, and I was granted all the opportunity and assistance from the representatives of the Cochlear Implant Centrum in Hannover to collect data, many children and their parents declined to participate in the study on the ground that children at the center were already over-loaded with their due regular testing.

A control group of 42 TD children (16 female) also participated in the study, a subset of the children participating in the study presented in Chapter 6. All TD children were also monolingual German speakers. The control children were aged 5;11 to 11;11 years (*M* = 9;4 *SD* = 1;6 years). According to audiometric screening, all control children were hearing normally, i.e., they had a pure tone hearing threshold of 20 dB Hearing Level (HL) or better at frequencies between 125 and 8000 Hz. All participating children's legal guardians gave written informed consent before testing and children received age-appropriate thank-you gifts for taking part in the experiment. The study was approved by the Ethics Committee of the University of Oldenburg and conducted in accordance with the Declaration of Helsinki.

Table 8.1. Individual participant profiles of the children with cochlear implants. All ages are given in years and months (y;m).

Participant	Chronological Age	Gender	Implantation age (1st CI)	Implantation age (2nd CI)	Hearing Age	Hearing Aid	Device
CI 01	7;1	M	2;5	2;5	4;8	Y(ONE)	CI 422(SRA) /Hearing Aid
CI 02	6;1	F	1;1	1;1	5;0	N	Concerto /Concerto
CI 03	11;1	M	1;11	1;11	9;1	N	Freedom/Freedom
CI 04	11;7	F	1;2	2;0	10;5	N	Freedom/Freedom
CI 05	11;9	M	1;5	1;5	10;4	N	HiRes90K/HIRes90K
CI 06	10;8	M	1;6	1;6	9;2	N	N/A
CI 07	11;11	F	1;6	4;0	10;5	N	N/A
CI 08	10;8	M	2;1	2;10	8;6	N	N/A

8.2.2. Working memory

To find out if there is an association between working memory capacity and performance on prepositions, four subtests from a standardized and computerized working memory test battery (Arbeitsgedächtnistestbatterie für Kinder im Alter von 5-12 Jahren (AGTB 5- 12)) (Hasselhorn et al., 2012) were used, namely, *one-syllable word span*, *digit forward span*, *Corsi block test* and *matrix span*. These subtests were designed to assess the phonological loop (*one-syllable word span* and *digit forward span*) and visuospatial sketchpad (*Corsi block test* and *matrix span*), respectively. Examining WM capacity through verbal and visual modality can allow for an unbiased testing of WM in children with CIs. Provided these children have language problems, this can affect their performance on the verbal WM task, which can result in incorrect assessment of their general WM skills. The information gathered from both modalities, however, can give us a fairer picture of the WM capacity of these children because visual WM performance should not be strongly affected by language problems.

Working Memory assessment procedure

One-Syllable Word Span Test. This test assesses the phonological store capacity by measuring the largest number of words that a participant can immediately recall in the correct order. Several sequences of the *one-syllable word span test* were auditorily presented by a computer with external speakers. Children were asked to recall and name the words in the correct chronological order directly after hearing the last word of the sequence. If the recall was right for two trials, the number of words in a sequence was increased by one (up to the maximum of nine words). If the recall failed for two trials, the number of words was decreased by one (down to the minimum of two words).

Digit Forward Span Test. It assesses the phonological store capacity by measuring the largest number of digits a participant can immediately recall in the correct order. Children listen to a number of digits from 1 to 9 auditorily presented by a computer with external speakers and are instructed to recall and name the digits in the correct chronological order directly after hearing the last digit of the sequence. The adaptive mechanism of this subtest is similar to the one in the *one-syllable word span test*.

Corsi Block Test. This test measures the participant's ability to remember series of spatial locations presented in the sequences of different lengths. In this test children were asked to memorize and reproduce the path of a painted face ('smiley') that moves randomly through an array of nine squares shown on the computer screen. If the participant reproduced the path correctly for two trials, the movement of the 'smiley' was increased by one step (up to the maximum of nine) and the path between the 'smiley' movements from square to square got longer. If the child failed to recall the path for two trials the movement was decreased by one (down to the minimum of two).

Matrix Span Test. The participant's score on this test reflects the participant's ability to memorize visual details without spatial change in the information. This subtest displayed a pattern on a chessboard with 16 fields, which disappears after four seconds. Afterwards children were asked to tap the remembered pattern on the touchscreen. The adaptive mechanism of this subtest is similar to the one in *Corsi block test*.

8.3. Statistical analysis

All statistical analyses were conducted using R (R Core Team, 2014). Generalized linear mixed-effects regression models (GLMER) were run using the lme4 package (Bates et al., 2013) for all analyses. Accuracy was modeled as a binomially distributed variable using a logit link function. The inclusion of factors in all models was assessed by comparing the Akaike-Information-Criterion scores (AIC; Akaike, 1974). A decrease of at least 2 in the AIC scores indicates that the inclusion of a factor improves the goodness of fit of the model. All *age* variables (including *hearing age*) were centered via a z-transformation prior to inclusion in all models.

To compare *Accuracy* on the comprehension task between the groups (children with CIs and TD children) a GLMER was made including random intercepts for *Participant* and *Item*. The necessity of including random slopes was assessed, but as a by-subject random slope for *Type of Preposition* did not improve model fit it was left out. One by one, the following fixed factors were added to see whether they improved the goodness of fit of the model: *Group* (children with CI vs. TD children), *Type of Preposition* (lexical prepositions vs. subcategorized prepositions), *Hearing Age* [18] (for children with CIs this was chronological age minus age at CI implantation, for TD children it was chronological age). The inclusion of *Type of Preposition* did not improve the model; hence, this factor was not included in the final model. In addition, no interaction was found between *Type of Preposition* and *Group*.

Since it was interesting to find out the effects of visual working memory measure and verbal working memory and not in the effects of particular subtest for each type of working memory, *Corsi block* and *matrix* subtest were combined using z-transform (see e.g.., Carroll, Warzybok, Kollmeier & Ruigendijk, 2016; Salthouse, 2004, p. 105 for similar procedures) into one visual working memory score. The same procedure was applied to combine the scores on *digit span* and *word span* subtests to calculate one verbal working memory score. A GLMER was run with *Accuracy* on the comprehension of prepositions as a dependent variable and *Group* and *Visual working memory* and *Verbal working Memory* scores as independent variables. Fixed factors (*Group, Visual working memory, Verbal working Memory*) were added one by one to the model with only random factors (*Item* and *Participant*). Since the inclusion of *Verbal working Memory* did not improve the model, it was not included in the final model.

For the statistical analysis of the production data GLMER was used as well.

18 Chronological age of children with CIs is also a significant predictor, but since hearing age and chronological age highly correlate, I did not include both (chronological and hearing age) in the same model. Hearing age is included in this model because it has a smaller *p*-value and leads to a lower AIC score, suggesting that it is a better predictor than chronological age.

Separate GLMERs were conducted for *contrastive elicitation task I* and *II*, because *contrastive elicitation task I* included both LexPs and SubPs whereas *contrastive elicitation task II* only LexPs. To compare the groups on *the contrastive elicitation task I* (children with CI and TD children) one model was made, including random intercepts for *Participant* and *Item*. The necessity of including random slopes was assessed, but as a by-subject random slope for *Type of Preposition* did not improve the model it was left out. The following fixed factors were sequentially added to see whether they improved the goodness of fit of the model: *Group* (children with CIs vs. TD children), *Type of Preposition* (lexical vs, subcategorized) and *Hearing Age*. The inclusion of *Type of Preposition* did not improve the model. As for the *contrastive elicitation task II*, another GLMER was run including random intercepts *Item* and *Participant*. Similarly to the model build-up procedure in the previous analysis, fixed factors *Group* and *Hearing Age* were added incrementally to the model.

8.4. Results

8.4.1. Comprehension

For children with CIs accuracy on LexP reached 62.0% (SD 18.4) while on SubP it was 64.2% (SD 18.0). For TD controls accuracy on LexP was 82.8% (SD 13.3) and on SubP 81.3% (SD 14.5) (Figure 8.1).

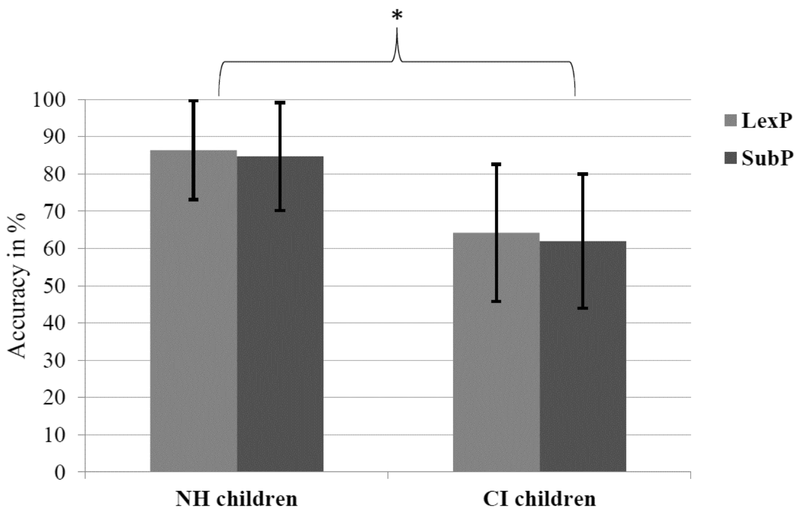


Figure 8.1. Performance on the sentence judgment task by CI and TD children (LexP= sentences with lexical prepositions, SubP=sentences with subcategorized prepositions).

In order to incorporate both, hit rates and false alarms, that is, to better detect bias in participants' judgments, accuracy of performance on the comprehension task was measured by d-prime. The d-prime measure of signal detection theory takes response bias into account by calculating the difference between the normalized hit and false alarm rates[19] (Macmillan & Creelman, 2005).

In the group with CIs, the mean d-prime value for LexP was 0.79 (SD 1.12) and the mean for SubP was 0.94 (SD 1.24). For TD controls, the means for both LexP and SubP were higher, namely, 2.17 (SD 0.99) and 1.98 (SD 1.06), respectively. This outcome shows us that TD children were more accurate in their judgments, meaning having fewer misses or false alarms than children with CIs.

The results of the final GLMER for the comprehension data are given in Table 8.2. There was a main effect of *Group* (CI vs. TD) showing that TD children are better on the comprehension of prepositions than children with CIs (Figure 8.1). Furthermore, a main effect of *Hearing Age* on accuracy of prepositions was found, revealing that for children with CIs, the longer they have auditory input, the better their comprehension of prepositions. For TD children, this outcome tells us that their performance improves with age. There was no interaction between *Group* and *Hearing Age*.

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Table 8.2. Fixed and random effects of best-fitting generalized mixed effects model to fit the accuracy scores on the sentence judgment task.

Predictor				
Random effects:	Variance	Std. deviation		
Items (Intercept)	0.06	0.25		
Participants (Intercept)	0.39	0.63		
Fixed factors:	Estimate	Std. Error	z-value	p-value
Group (CI vs. TD)	-0.38	0.13	2.82	0.004
Hearing Age	0.52	0.10	4.80	<0.001
Group x Hearing Age	-0.05	0.10	-0.51	0.6

The final model including *Accuracy* as a dependent variable and *Group* and *Visual working memory* and *Verbal working Memory* as independent variables is summarized in Table 8.3. The GLMER analysis revealed a main effect of *Group* which confirms that TD children and children with CIs differ on the comprehension of prepositions. Furthermore, a main effect of *Visual working memory* (but not of *Verbal working memory*) was found revealing that the better children perform on *Visual working memory* the better their accuracy on the comprehension of prepositions. There was no

19 The formula for calculation of d-prime is $d'=z(H)-z(FA)$, where H=hit rate, FA=false alarm and z-transform is based on the standard normal distribution.

interaction between *Group* and *Visual working memory* showing that comprehension of prepositions is similarly associated with this measure in both groups.

Table 8.3. Random and fixed effects of best-fitting GLMER for testing the effects of working memory measures on the comprehension of prepositions.

Predictor				
Random effects:	Variance	Std. deviation		
Items (Intercept)	0.06	0.24		
Participants (Intercept)	0.49	0.70		
Fixed factors:	Estimate	Std. Error	z-value	p-value
Group (CI vs. TD)	-0.62	0.15	-3.96	<0.001
Visual WM	0.40	0.15	2.65	0.007

Because the sample of children with CIs is relatively small (*n*=8), the accuracy data in individual children was also explored. It was calculated how many children with CIs were able to perform above chance. The range for chance performance was determined by a binomial test ($P_{correct}$ = 0.5, n = 82, α = 0.05) to be 34 to 48 (of 82, i.e., 41.5% - 58.5%) items correct per sentence type (LexP or SubP sentences). The individual results of the comprehension experiment are given in Figure 8.2.

Exploring the individual data for chance performance by children with CIs suggests that not only *Hearing age* but also implantation age influences how these children do on the comprehension task. In Figure 8.2, we see that children implanted relatively late, i.e., children CI 01, CI 03 and CI 08 (at 2;5, 1;11 and 2;2 years, respectively) do not perform better than chance. There is one exception, namely the child implanted at 1;1 year who performs not better than chance, however, this participant is the youngest in the group and despite relatively early implantation age has a lower hearing age and hence less time to catch up.

To test the effect of implantation age on the comprehension accuracy in my sample of children with CIs statistically, a GLMER with *Accuracy* as a dependent variable and *Type of Preposition, Hearing Age* and *Implantation* Age as fixed factors was run. As the factor *Type of Preposition* did not improve the model it was excluded from the final model. The outcomes of this analysis are summarized in Table 8.4.

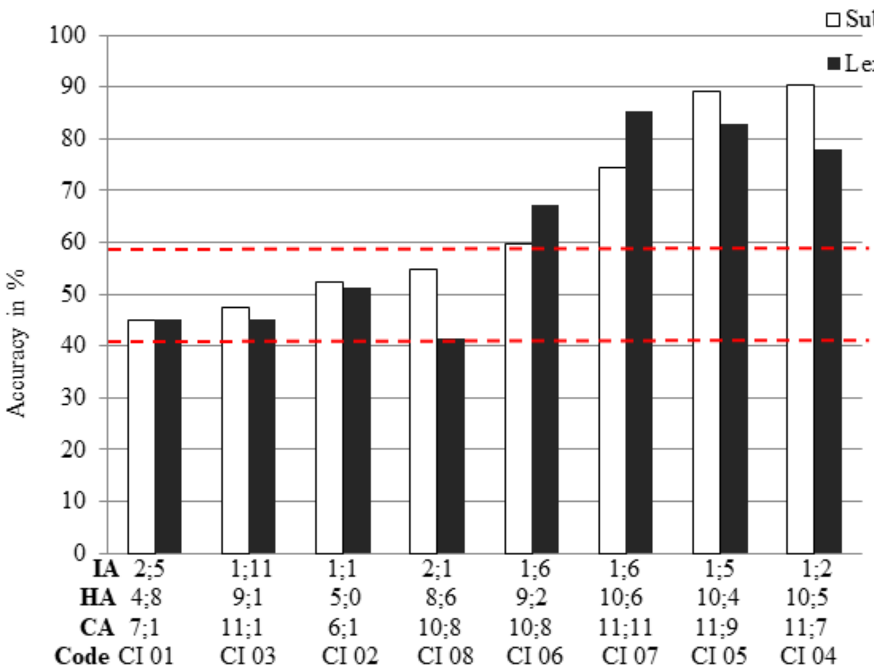

Figure 8.2. Individual performance of children with CIs on the comprehension task. The grey bars show the percentage accurate performance on SubP and the black bars on LexP. The red dashed lines represent the cutoff range for chance performance determined by binomial test. Performance of the children who scored between the cutoff lines was not significantly different from chance. IA=implantation age; HA=hearing age; CA=chronological age: Code=participant codes. All ages are given in years and months (y;m). Participants are ordered by increasing performance on SubP sentences.

Table 8.4. Fixed effects of best-fitting GLMER for testing the effects of implantation age on the comprehension of prepositions.

Predictor				
Random effects:	Variance	Std. deviation		
Items (Intercept)	$3.3*10^{-10}$	$1.8*10^{-5}$		
Participants (Intercept)	0.17	0.41		
Fixed factors:	Estimate	Std. Error	z-value	p-value
Hearing age	0.36	0.13	2.68	0.007
Implantation Age	-0.49	0.23	-2.09	0.03

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As we can see from Table 8.4, both *Hearing age* and *Implantation Age* have a significant effect on the *Accuracy*. Thus, the earlier children are implanted the better and the longer hearing experience the better.

8.4.2. Production

On average, TD children correctly produced 98.5% of LexP and 99.2% of SubP sentences on the *contrastive elicitation task I*, while on *contrastive elicitation task II* 94.0% of the sentences were produced correctly. As a group (including all 8 participants), children with CIs reached 90.6% correct on lexical and 89.5% correct on the subcategorized prepositions on the *contrastive elicitation task I*. *Contrastive elicitation task II* reached 90.6% performance.

With regard to the types of mistakes that children with CIs made on *contrastive elicitation task I,* they included both omissions and incorrect substitutions. In total, there were 19 incorrect responses on *task I* (both omissions and incorrect substitutions) out of 192 trials (i.e., 24 experimental sentences x 8 participants with CIs). The omissions comprised 42% of the total number of the mistakes made (i.e., 8 out of total 19), while the rest were incorrect substitutions. The distribution of mistakes per prepositions type was roughly the same (difference of only one mistake).

On *contrastive elicitation task* II only omission mistakes were made (no incorrect substitutions), specifically, there were 9 omissions out of 96 trials (12 sentences x 8 participants). In comparison, TD children made virtually no incorrect substitution mistakes (only one case per *contrastive elicitation task*). Their mistakes represented omissions of the prepositions.

Regarding the mistakes made by children with CIs, it is important to note that almost half (47%) of all mistakes (i.e., 13 out of 28) on both tasks together were made by one child, namely, child CI 01.

In Table 8.5, we summarize the outcomes of the GLMER analysis of the *contrastive elicitation task I*. The factors Group and Hearing Age as well as the interaction between *Group* and *Hearing Age* are listed in the analysis summary. The analysis revealed a main effect of *Group* and *Hearing Age*, but no effect of the interaction *Group* and *Hearing Age*. Hence, on *contrastive elicitation task I* TD children significantly outperformed children with CIs. Furthermore, the longer CI users have had their implants the better their outcomes (for TD children this means that with age their performance improves). As there is no interaction between *Group* and *Hearing Age*, we see that the performance in both groups significantly improves similarly over time.

Table 8.5. Summary of the GLMER analysis of the contrastive elicitation task I.

Predictor				
Random effects:	Variance	Std. deviation		
Items (Intercept)	0.55	0.74		
Participants (Intercept)	0.31	0.55		
Fixed factors:	Estimate	Std. Error	z-value	p-value
Group	0.83	0.26	3.13	0.001
Hearing Age	-0.51	0.21	-2.42	0.01
Group x Hearing Age	-0.19	0.21	-0.90	0.36

For the *contrastive elicitation task II*, none of the factors improved the model revealing that that there is no difference between TD and children with CIs on this measure.

Individual performance of children with CIs was assessed for the *contrastive elicitation task I* (both LexP and SubP together as there was no difference of *Type of Preposition*). For this purpose, a cutoff for the normal range of performance was defined to be at 5 percentile. All children with CIs, but CI 01, who was also the youngest, fell into the normal range of performance. This particular child produced only 58.3% of lexical and the same 58.3% of subcategorized prepositions correct on the *contrastive elicitation task I*.

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8.5. Discussion

In this study, the comprehension and production of lexical and subcategorized prepositions in German-speaking children with CIs was examined. Prepositions can be potentially difficult to master for children with CIs. There are several reasons why prepositions can be challenging. Firstly, being short in length and typically not in a stressed position, prepositions are not perceptually salient in the flow of speech stream. During language acquisition highly salient elements typically emerge earlier in children's language than non-salient ones (Zobl & Liceras 1994). Therefore, especially in the conditions of degraded auditory speech stimuli that children with CIs receive, prepositions can be even harder to discriminate in the speech stream than under normal hearing conditions. This reduced perceptual salience of prepositions can have an even higher impact on the acquisition of prepositions by these children than it does in children with TD. Furthermore, prepositions can be not only perceptually difficult, but also conceptually confusing in the process of acquisition as they are often polysemous. For example, as discussed in Chapter 2, phonologically and orthographically identical prepositions can have very distinct meanings (e.g., temporal and locational). In addition, the linguistic function of prepositions is not straightforwardly mapped to their phonetic form. Theoretical (Corver & Riemsdijk, 2001; Zwarts, 1997) and experimental (the study in Chapter 5 of this thesis) research shows that phonologically and orthographically identical prepositions can be used in different linguistic functions, namely, they can be used either like lexical or functional category words. Hence, while prepositions are less salient, they can carry distinct grammatical and semantic information and a child has to not only discriminate these short words from the speech, but also to assess their linguistic properties such as meaning and function.

Comprehension

To study the comprehension of lexical and subcategorized prepositions in children with CIs, a sentence judgment task was employed. CI children's comprehension was compared to that of TD age-matched children. As hypothesized, the data revealed that prepositions are problematic in children with CIs as they performed significantly poorer than TD peers. The poor performance by CI children on the comprehension of prepositions could be ascribed to low perceptual salience of these words. Previous evidence has demonstrated that language development in these children is strongly affected by the perceptual salience of linguistic forms. For instance, Svirsky et al (2002) showed that the acquisition of the perceptually more salient English copula -'is' and 'are'- precedes the acquisition of noun plurals in children with CIs. Interestingly, these results were in direct contrast with those obtained from TD children who showed greater proficiency in the use of noun plurals than in the use of the copula. Szagun (2004) found that in children with CIs the article system – a category typically having low perceptual salience, was less developed than in TD children, despite high frequencies of definite articles in the input speech.

From previous findings we know that children with CIs experience difficulties with words carrying grammatical information, i.e., functional words such as determiners (Szagun, 2000; Le Normand, 2003). Therefore, the purpose of examining phonologically identical prepositions in functional (subcategorized prepositions) and lexical (lexical prepositions) use was to see whether the respective linguistic properties affect acquisition when phonological salience is accounted for. It was expected that children with CIs would do better on lexical than on subcategorized prepositions as the latter share linguistic properties with function words. Contrary to the expectations, no difference was found on the performance of these two types of prepositions. An explanation for this outcome could be the characteristics of the participant sample. We know from previous research that problems with grammatical constructions are most prevalent in younger children with CIs but tend to resolve with age (Hammer, 2010). In this sample, there were only 2 young children (CI 01 and CI 02, aged between 6 – 7 years), while the other participants were older than 10 years. Examining younger children with CIs or children with a lower hearing age could shed a better light on whether less salient subcategorized prepositions are more difficult to acquire. In the beginning of this chapter, I hypothesized that if the performance by children with CIs on prepositions would improve with age, this would suggest a delayed development of this category, whereas, if one or both types of prepositions (lexical and subcategorized) remained problematic for both younger and older children, this would suggest impairment (or atypical development) of this category. Since children with CIs performed on the comprehension of lexical and subcategorized prepositions on a similar level, and since their performance on both types of prepositions improved with hearing age, the acquisition of prepositions appears to be delayed rather than impaired in these children.

So far, I have discussed the performance by children with CIs on the comprehension of prepositions as a group. In line with many previous studies in this population (e.g., Szagun 2001; Gillis et al., 2002; Svirsky, Teoh, & Neuburger, 2004; Duchesne et al., 2009; Le Normand et al., 2003), there was considerable inter-participant variability in performance. Half of the CI users were not able to comprehend prepositions better than chance, while the other half was above chance level and there were children who performed similarly well to TD children. The statistical analyses revealed that both hearing age and age at implantation were factors influencing the comprehension results. The earlier children were implanted and the longer their hearing experience was, the better their performance turned out. In terms of age at implantation, there was one child who was implanted relatively early (CI 02 at age: 1;1 years) whose outcome on the comprehension of prepositions was not better than chance and as such was an exception. However, this particular child was also the youngest in the sample and had relatively low hearing age (5;0 years), whereas the hearing age of the other children in my sample ranged from 8;6 to 10;4 years. Available literature on the association of implantation age with language outcome of children with CIs shows that some of the variability is explained by this factor. This is in line with the finding of the present study. The argumentation is that the earlier children receive their implants, the better their language outcomes. There is evidence that language skills of children implanted at 12 months were better than those implanted at 24 months (Tomblin, Barker, Spencer, Zhang & Gantz, 2005). In another study, children implanted between 12 and 16 months were more likely to achieve age-appropriate spoken language than children implanted after 24 months (Nicholas & Geers, 2007). Schouwenaars et al. (2019) demonstrated that the earlier children are implanted, the better their perception of morphosyntactic cues (case and subject-verb agreement) was. Thus, similarly to these studies my study also demonstrates the benefits of early implantation.

Besides the age at implantation, studies have evidenced the importance of hearing age as an explanation of variability on the language outcomes of children with CIs. For example, Hammer (2010) found that hearing age was a predicting factor for finite verb production in children with CIs. According to Schouwenaars et al. (2019) hearing age was a significant predictor for the comprehension of *which*-questions in children with CIs. Similarly, I found that the comprehension of prepositions is predicted by hearing age, that is, the older children's hearing age and thus the longer their language experience the better they perform. This finding implies that the problems we see in children with lower hearing age may be overcome and that, as noted above, the difficulties they experience with preposition can be considered a delay rather than impairment.

Some of the variability in language outcomes of children with CIs is explained by their working memory capacities (e.g., Kronenberger et al, 2011; Schouwenaars et al., 2019). Working memory is considered to influence a range of language skills in children (e.g., vocabulary acquisition, sentence comprehension) and is critical for language development as the growth of working memory skills has been linked to improvement in language skills with age (Hansson et al., 2004, Pickering & Gathercole, 2001; Pisoni et al., 2010). Studies have pointed to limitations of working memory in children with CIs (Kronenberger et al, 2011). According to many studies, CI users score below age norms on measures of auditory working memory (e.g., Pisoni & Cleary, 2003; Pisoni et al., 2008). When it comes to visual working memory, some research suggests that visual memory spans and some visual sequencing skills of individuals with CIs also fall below average compared to TD peers (Cleary, Pisoni, & Geers, 2001; Pisoni & Cleary, 2004), whereas evidence suggests that children with CIs perform at par with TD children on tasks of visuospatial working memory (Wass et al, 2008; Lyxell et al, 2008). The present study investigated the role of these two aspects of working memory, namely, verbal working memory and visual working memory on the comprehension of prepositions. It was found that only visual working memory and not verbal working memory was a predictor for the comprehension of prepositions in children with CIs. Interestingly, I found no interaction between group (CI vs. TD) and visual working memory which shows that visual working memory is a comparable predictor for both groups and that there are no differences between TD children and children with CIs in this respect. Visual working memory can be a good predictor for language outcomes (Wass et al, 2008; Lyxell et al, 2008) and the two groups I tested were comparable on this particular cognitive skill. Thus, one could assume that the preposition comprehension problems that children with CIs in my sample experience are indicative of the delay of their language development rather than their non-verbal cognitive skills. However, a logical question here is why I found visual working memory to be a predictor for the comprehension of prepositions and not verbal working memory. Interestingly, a somewhat similarly unexpected role for the visuospatial system on comprehension was found in a study of the grammatical capacity of people with Williams's syndrome by Phillips and colleagues (2004). They compared a series of grammatical structures that involved spatial terms (e.g., above, below, in, shorter, etc.) to nonspatial constructions (e.g., neither/nor, X is but Y is not, etc.) and found that people with William's syndrome were grossly impaired on spatial terms such as prepositions. The authors suggested that the problems with these spatial terms arose because these individuals were impaired on visual working memory and concluded that the ability to maintain and manipulate information of a visuospatial nature is likely to play an important role in the comprehension of certain types of linguistic items such as prepositions. The findings of Phillips et al. (2004) study could be related to the results of the current study regarding the role of visual working memory to the comprehension of prepositions. Their suggests that visual working memory can be more related to the processing of prepositions than verbal working memory capacity.

Production

Contrastive elicitation tasks (I and II) were used to study the production of prepositions in children with CIs, with TD children serving as a control group. Overall, children with CIs scored well on both tasks. I found no statistical differences between children with CIs and their TD peers on the *contrastive elicitation task II* which involved the production of only lexical prepositions. Although children with CIs scored quite high on *contrastive elicitation task I*, which tested both lexical and subcategorized prepositions, they were still outperformed by TD children as a group. In the second step, the individual outcomes of children with CIs on this task were studied. It was found that all children except one (CI 01) scored in the normal range. Why did this child show such poor performance? The age at implantation and hearing age alone cannot explain this result as there are more children in the CI sample with relatively late age at implantation and/or short hearing age. In contrast to other children in the sample however, he had a CI on one ear and a hearing aid on the other, instead of two CIs like the other children in the sample of the study. This fact could explain his poor outcomes because past studies show that in conditions of profound hearing loss children wearing CIs develop language faster than children using conventional hearing aids (Geers & Moog, 1994; Geers, Nicholas,

& Sedey, 2003; Svirsky, Robbins, Iler-Kirk, Pisoni, & Miyamoto, 2000). However, with this one particular case in the study, it would be hard to draw definitive conclusions regarding the role of bilateral CI in the production of prepositions.

Conclusion

The study presented in this chapter demonstrated that in comparison to TD children, children with CIs are delayed in the comprehension and production of lexical and subcategorized prepositions. Although the data seem to suggest that children perform better on the production than on the comprehension of prepositions, this conclusion cannot be draw definitively, as the experiments run in this study were not designed to compare comprehension and production of prepositions directly. While in the comprehension experiment children had to process a specific preposition, on the production experiment they were less restricted to producing specific prepositions as they could use an alternative preposition that correctly described the picture and hence had more freedom in choice on the production than on the comprehension experiment.

The performance on the comprehension of both types of prepositions was associated with age at implantation and hearing age. With longer hearing experience children with CIs improve their performance and catch up with TD children. It was furthermore found that visual working memory is a predictor for the comprehension of prepositions.

Since prepositions are very frequent in language and can carry distinct meanings and linguistic functions, it is essential that children master them during language acquisition. Children with CIs show a significant delay in the mastery of prepositions as demonstrated in the study presented here. This delay can affect the quality of their everyday communication and even the learning process at school. Therefore, it is advisable that clinicians who work on language skills of these children pay particular attention to prepositions. This could be achieved by for example, employing activities directed at highlighting obligatory contexts for the use of prepositions or in some cases by visually depicting preposition meanings and the consequences of incorrect substitutions.

Chapter 9.

General Discussion

The purpose of this dissertation was to study the processing and acquisition of German prepositions. Prepositions were tested in two types of usage, namely, lexical (lexical prepositions), when prepositions convey meaning, and functional (subcategorized prepositions), when prepositions have essentially no meaning and fulfill primarily a structural purpose. In total, four studies were conducted and, although each of these studies had specific research questions, the general research questions this dissertation pursued to answer were:

How are prepositions processed in the human brain? That is, can we find language processing evidence to resolve the problem of the syntactic categorization of prepositions into lexical/functional categories?

- How are prepositions processed in the developing brain?
- Is there a difference in the comprehension and/or production of prepositions between lexical (meaningful) vs. functional (virtually meaningless) usage?
- How are the prepositions in lexical and functional usage acquired by children with profound hearing impairment wearing CIs? Does the fact that prepositions are typically not perceptual salient affect the acquisition of prepositions?

Three groups of participants were recruited for the experiments conducted to address these questions. The first group comprised healthy adults, who took part in the ERP experiment (Chapter 5). The purpose of this ERP experiment was to determine whether there is neurophysiological processing evidence regarding the classification of prepositions into lexical or functional category words, or, whether prepositions can be used in some instances as lexical and in others as functional and thus be a hybrid between the two categories. As noted in Chapter 2, theoretical research is not completely clear regarding the syntactic categorization of prepositions. While some theoreticians believe that prepositions should be classed as lexical category words together with nouns, verbs and adjectives (e.g., Jackendoff, 1977), there are a number of researchers who support the classification of prepositions as functional category words together with determiners and complementizers (e.g., Grimshaw, 1991; Baker, 2003; Botwinik-Rotem, 2004). In addition to this bipartite division of prepositions into either one or the other category, there are researchers who suggest that prepositions can be a hybrid between the two categories and, depending on their usage, can exhibit properties typically associated with lexical or functional words (Zwarts, 1997, Littlefield, 2006/7). It is well-established that violations (or dispreferred usage) of lexical category words are processed qualitatively differently from violations (or ambiguous, dispreferred usage) of words and morphemes belonging to functional categories (e.g., Pulvermüller, Lutzenberger & Birbaumer, 1995). As discussed extensively in the background part of this thesis (Chapter 3), studies on ERP processi ng have provided evidence for a separation between lexical-semantic and syntactic/structural processing (Brown, et al., 1999; Neville et al., 1992). The ERP component traditionally associated with the processing of semantic information is the N400, whereas the ERP components that have been elicited for (morpho)syntactical processing violations and/or difficulties are the P600 (or late positive) component and (E)LAN (e.g., Osterhout et al., 1994; Kaan, 2007; Kaan & Swaab, 2003; Friederici, 2011; for a review see Bornkessel-Schlesewsky & Schlesewsky, 2009).

Using this ERP evidence as the premise, I hypothesized in Chapter 5 on the ERP study with adult mono-lingual German-speakers, that if prepositions are more like lexical category words, their violations or dispreferred usage should be processed accordingly in the human brain, whereas if they are more like functional category words, their violations or dispreferred usage should be processed similarly to those of functional categories. If prepositions are a hybrid between the two categories, however, the processing of their violations or dispreferred usage should exhibit both types of processing depending on how they are used, i.e., lexically (loaded with meaning) or functionally (meaningless). Two well-established ERP components namely, the N400 and the P600 were used as markers of the processing type to study the categorization question.

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The main finding of the ERP study presented in chapter 5 was that violations and dispreferred usage of lexical prepositions are processed more like lexical categories (e.g., Kutas & Hillyard, 1980; Friederici, Hahne, & Saddy, 2002), as they elicited an N400 in violated or dispreferred contexts. Violations and dispreferred usage of subcategorized prepositions (functional use), however, are processed more like functional categories, eliciting a P600 when violated or dispreferred (e.g., Kaan, 2007; Kaan & Swaab, 2003; Bornkessel-Schlesewsky & Schlesewsky, 2009). These results evidence that prepositions are neither a purely functional nor a purely lexical category but form a hybrid between the two categories. Depending on their usage, they can be processed like lexical or like functional category words.

Two studies with mono-lingual German-speaking TD children are reported in this dissertation. One study examined the comprehension and production of prepositions in lexical and functional use (Chapter 6) and the other explored the online processing of prepositions (lexical and functional usage) in an ERP study (Chapter 7). Prepositions represent an interesting category to study the acquisition of lexical and functional words because phonologically identical prepositions can be used both lexically or functionally. This possibility allows one to examine whether lexical or functional properties play a role in the development of the lexicon in children, when such parameters as word length or a phonological form are controlled for. In the background part of this dissertation, in Chapter 2, I have discussed why prepositions could be challenging during language acquisition and therefore represent an interesting class of words to study. To repeat, prepositions can be confusing for children, as they are often polysemous (see Chapter 2, for temporal and locational meanings of identical preposition), phonologically identical prepositions can have the properties of lexical or functional categories depending on usage and typically they are not stressed and short in length, thus being perceptually not salient. As a result, a child confronts the task of discriminating these perceptually non-salient words from the speech, as well as having to assess their linguistic properties such as meaning and function.

In this thesis, the goal of the studies with children was to better understand how they acquire phonologically and orthographically identical prepositions in lexical and functional uses. For this purpose, comprehension and production experiments were conducted. In these experiments, I examined whether there is a distinction in the acquisition of phonologically identical prepositions in lexical and functional use due to their differences in linguistic features such as absence or presence of (semantic) meaning. Another goal of these behavioral experiments with TD children concerned the role of age in the comprehension and production of prepositions. Taken together, the results on the comprehension of lexical and subcategorized prepositions showed that on average, above 10 years of age children's mastery of both types of prepositions improves and by the age of 12-13 years reaches adult levels. Similar improvement of the processing of prepositions with age was also reported in the studies by Friederici (1983) and Grimm (1975).

In contrast to general findings in language acquisition research that meaningful words are easier for children to process (comprehend in this case), no clear evidence of this phenomenon has been reported for prepositions. As shown in Chapter 6, the comprehension of meaningless subcategorized prepositions did not prove to be more difficult for children than lexical prepositions. This outcome can be explained by the fact that very few young children (< 9 years) participated in the study presented in this thesis. Considering the evidence in literature, for example the study by Grimm (1975), it is reasonable to assume that younger children, i.e., 4 – 6-year-olds perform better on meaningful than on meaningless prepositions. In fact, as I have argued in Chapter 6, a closer inspection of the individual results of younger children (> 10 years) shows that there is much more variation in the performance and there is a tendency for meaningless prepositions to elicit lower scores than meaningful ones. In conclusion, this behavioral study with TD children showed that children younger than 11 years have not yet reached adult performance level on the comprehension of prepositions neither in lexical nor in functional use. There seems to be no difference in the acquisition of lexical vs. functional properties of prepositions as no differences either on the comprehension or production between two uses of prepositions were found.

In the second study involving German-speaking TD children (Chapter 7), ERP effects of the processing of prepositions in lexical and functional use was explored. In the experiment with adults qualitatively distinct ERP components in association to lexical and functional use of prepositions were found. However, this processing distinction cannot be presupposed to exist in the developing brain as well. Behavioral studies on the acquisition of prepositions have shown that children typically process all prepositions as having meaning (e.g., Grimm, 1975) and only later discover the non-conceptual, more functional use of prepositions. Children, at least in the participant sample described in Chapter 7, did not show processing effects in association to the dispreferred usage of either lexical or subcategorized prepositions. For the semantically anomalous nouns in the control sentences, however, children displayed an N400 effect. The fact that children did not show processing effects of incongruent prepositions (and nouns in their context), but did show the processing effects for the semantic anomaly in control sentences *without* prepositions, leads to the assumption that the absence of the ERP effects could be ascribed to prepositions. This outcome is somewhat surprising taking into account children's accuracy scores on congruent and incongruent LexP and SubP sentences offline. Although they did not perform as well as adults did (adult's outcomes are reported in Chapter 5), children's offline accuracy performance reached 87.9% on LexP and 86.4% on SubP sentences. Such a performance still suggests that they were usually able to judge the congruity of the sentences. As I have argued in Chapter 7, although no evidence was found for the ERP effects in LexP and SubP sentences, one could consider the possibility of delayed effects, which did not show up in the statistical analysis. The reasoning behind this assumption is that, on one hand, children are believed to have slower processing speed than adults (Kail, 1991) and on the other, prepositions could have taken children even longer to be processed because of their polysemy, distinct usage (as lexical or functional) and low salience. The combination of these properties could have delayed children to access the appropriate function and meaning of the prepositions. In sum, one could speculate whether the congruity processing has occurred later, that is, in the later time slot than tested in the study. Still another possible reason as to why no ERP effects were found in LexP and SubP sentences can be the variability in the child sample participating in the study. I presented a literature review on the ERP effects in children in Chapter 3, which demonstrated that children's ERP components reflecting lexical-semantic and morpho-syntactic processing appear to change in their latency and duration with age (e.g, Friederici, 2006). In the participant sample tested, children's ages ranged from 6 to 13 years which could have potentially affected the latency and duration of the effects in terms of statistical power. In summary, this ERP study with children did not find clear evidence that children are sensitive to incongruent prepositions, whether in lexical or functional use. As I have speculated in Chapter 7, it is not unreasonable to assume that processing effects may have occurred later. The possibility that children could probably be not completely indifferent to the difference between the processing of lexical and subcategorized prepositions was shown in the final analysis of the ERP data. In this analysis, the processing of the LexP sentences was compared to the processing of SubP sentences (congruent and incongruent collapsed together), as a result of which a difference was revealed between the two uses of prepositions. However, because this analysis diverges from the traditional ERP analysis as noted in Chapter 7, no conclusions regarding the specific ERP components can be made in association of this processing outcome. What this processing results could tentatively suggest is that the developing brain makes some distinction between the two uses of prepositions.

The fourth study presented in this dissertation concerns the comprehension and production of prepositions in lexical and functional use in German-speaking children with CIs (Chapter 8). Taking into account their linguistic features, such as being short in length and typically unstressed, prepositions are not perceptually salient in the flow of speech and as such are bound to be challenging especially for children with CIs. Furthermore, as in the case of TD children, linguistic properties of prepositions such as the presence or absence of meaning as well as polysemy, can be confusing in the process of acquisition. While prepositions have low perceptual salience, which is particularly relevant when studying language acquisition in children with CI, they can exhibit different linguistic properties. As a result, children with CI face a two-fold challenge: not only do they have to discriminate these non-salient words in the speech stream, but they also have to find out their linguistic properties. As discussed in Chapter 8, the results of the comprehension of prepositions revealed that they are problematic for children with CIs. They performed significantly worse than TD peers on the task. This outcome shows that most likely the low perceptual salience plays a role in the acquisition of prepositions by children with CIs. The purpose of examining phonologically identical prepositions in functional (subcategorized prepositions) and lexical (lexical prepositions) use was to examine whether the respective linguistic properties affect acquisition when phonological form is accounted for. This is particularly relevant for children with CIs, because phonological form can be a confounding factor for interpreting the results of the performance when lexical and functional words are tested. In this respect, there was no difference found between the two types of prepositions in children with CIs. This study furthermore showed considerable inter-participant variability in performance, which was partially explained by implantation age and the length of the hearing experience (hearing age) of these children. Furthermore, the study revealed that some of the variability in language outcomes of children with CIs is accounted for by their working memory capacities (e.g., Kronenberger et al., 2011; Schouwenaars et al., 2019). Although some children with CIs comprehend prepositions at level with their age peers, there are also those who still struggle with these words. In line with previous findings regarding the role of the implantation and hearing ages for the language development in children with CIs (e.g., Nicholas & Geers, 2007; Hammer, 2010; Schouwenaars et al., 2019), these two factors also play an important role in the comprehension of prepositions in this population. These findings mean that if children are implanted timely, that is, at the age of six months (or soon after) (Geers & Moog, 1994; Geers, Nicholas & Sedey, 2003; Svirsky et al., 2000) and thus are exposed to language from early on, they should be able to master prepositions on a level similar to that of their age-matched peers.

On the production of prepositions, TD children outperformed children with CIs as a group. However, as I have reported in Chapter 8, looking at the performance of CI children individually revealed that all but one of the children scored in the normal range. In contrast to other children in my sample however, this one child had a CI on one ear and a hearing aid on the other, instead of two CIs like the rest of the children. This fact could explain his poor outcomes. As suggested by past research, children who are implanted with CIs develop language faster than children with profound hearing loss using conventional hearing aids because hearing aids provide no or only little benefit for children with this type of hearing loss (Geers & Moog, 1994; Geers, Nicholas & Sedey, 2003; Svirsky, Robbins, Iler-Kirk, Pisoni, & Miyamoto, 2000; Tomblin, Spencer, Flock, Tyler & Gantz, 1999). In sum, children with CIs show a significant delay in the mastery of prepositions as demonstrated in this work. This delay can affect the quality of their communication in everyday life and present a hindrance even in the learning process at school. Therefore, it is advisable that clinicians who work on language skills of these children pay particular attention to prepositions. This could be achieved by for example, employing activities directed at highlighting the obligatory contexts for the use of prepositions or in some cases by visually depicting preposition meanings and the consequences of incorrect substitutions.

9.2. Future directions

Although the findings presented in this dissertation provide important implications for the processing of prepositions in adults, TD children and children with CIs, future studies would help to further elucidate the issues regarding the processing of prepositions in these populations.

One major finding in the study with adult participants was the qualitatively distinct neurophysiological underpinnings associated with the processing of lexical and subcategorized prepositions. This finding serves as an implication for the categorization of prepositions into a hybrid between lexical and functional categories. That is, prepositions as a whole class are neither lexical nor functional, but rather depending on their usage, can have properties of lexical and functional categories. In future, it would be interesting to extend the study of ERP processing of prepositions to the syntactic usage of prepositions (e.g., passive *by*). The finding that prepositions are a hybrid between lexical and functional category presented in this dissertation can only be applied to prepositions used as lexical and subcategorized. Testing prepositions in syntactic usage as well can help to fully understand the categorization question of all prepositions. Taking into account the properties and usage of syntactic prepositions which are strictly structural, for example, the preposition *by* is selected when a passive agent is needed, one would expect to find ERP processing effects such as an (E)LAN and/or a P600 when such prepositions are violated or used in dispreferred contexts.

Contrary to the past evidence from the language acquisition literature that words (or morphemes) that lack meaning are more challenging for children than words with meaning, in the comprehension and production study with TD children no difference was detected between lexical and functional usage of prepositions, at least in the sample of children whose ages ranged from 6 – 13 years. In future, it would be informative to test younger children, i.e., below the age of 6 years on the comprehension and production of the prepositions as the acquisition differences between lexical and functional categories, if at all, should be most pronounced at these younger ages (Radford, 1990). As a result, we could be better informed, whether functional words are more challenging in the process of acquisition than lexical ones and this is not necessarily because of the shortness and low salience of functional words (as prepositions in lexical and functional use can have identical phonological form), but perhaps because of such factors as presence/absence of meaning.

The ERP experiments with TD children did not find clear evidence as to how the developing brain processes prepositions in lexical and functional use. In Chapter 7, I proposed the possibility of delayed effects reflecting the processing of incongruent prepositions. Future research still has to confirm whether indeed any effects occur later. This could be achieved through an experimental design which allows for ERP analysis in the later time windows. Besides an ERP experiment, a reaction time study can yield interesting results concerning the processing speed of prepositions in children. Furthermore, to decrease the variability in the data, which is particularly relevant for EEG data, it would be advisable to recruit a relatively homogeneous group of participants with a narrower age range than in the study presented here.

In Chapter 8, it was shown that children with CIs performed significantly worse than their TD peers on the comprehension of lexical and subcategorized prepositions. Although this study reports the important finding that children with CIs find prepositions challenging, this behavioral study informs us about how these children perform offline, that is, about the end product of the processing. However, what we do not learn from this study is, what happens *during* the processing of prepositions in sentence contexts. Therefore, an online study, e.g., a reaction time or an ERP study, can extend our understanding as regards to the challenges these children experience with prepositions.

9.3. Conclusion

The important implication of this work is that, as demonstrated in the ERP study with adults, in terms of syntactic categorization, prepositions can be classed as a hybrid between lexical and functional categories, as they can have properties of both categories depending on usage. Children seem not to detect incongruent prepositions neither in lexical nor in functional use, although they are not completely indifferent to the processing of sentences with lexical and subcategorized prepositions and showed distinct processing for LexP and SubP sentences (when congruent and incongruent sentences were collapsed together for each type). After the age of 10 years, TD children's comprehension and production of prepositions becomes similar to that of adults. Children with CIs lag behind their TD peers on the comprehension of prepositions, which can present serious obstacles in everyday language use for them. Clinicians are encouraged to design special exercises to enhance the acquisition of prepositions in children with CIs.

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About the author

Mari Chanturidze was born in Rustavi, Georgia, on September 27, 1979. After finishing her secondary education, she went on to study English language and culture at Tbilisi State University of Language and Culture. Subsequently, she completed a two-year master in linguistics at the same university. In 2009, she was awarded the Utrecht Excellence Scholarship to start the research master ***Linguistics: The Study of Language Faculty***.

In May 2013, Mari obtained a scholarship for a PhD project in the Signals and Cognition program at Oldenburg University, Germany. In her PhD project she investigated the processing of German prepositions through a series of behavioral and ERP experiments with German-speaking adults, typically developing children and children with cochlear implants. In the meantime, she also became the mother of three children.

A

Appendices

Appendix A: stimuli used in the comprehension experiment

Table A-1. Repetition count of each preposition per sentence type (SubP and LexP) and per condition (congruent and incongruent).

SubP congruent	N	SubP incongruent	N	LexP congruent	N	LexP incongruent	N
auf	6	auf	4	auf	7	auf	3
nach	7	nach	2	nach	4	nach	6
von	8	von	7	von	2	von	1
mit	5	mit	2	mit	5	mit	9
an	6	an	5	an	4	an	1
zu	2	zu	4	zu	2	zu	9
für	6	für	3	für	0	für	3
um	0	um	6	um	1	um	0
aus	0	aus	2	aus	2	aus	2
vor	1	vor	1	vor	2	vor	2
bei	0	bei	2	bei	5	bei	2
in	0	in	3	in	7	in	3

N=times used

A

Experimental sentences and their English translations[20]

Der Zoologe sorgt für eine Katze
The zoologist looks after a cat
Der Zoologe sorgt in eine Katze
The zoologist looks in a cat
Der Opa zeigt auf einen Berg
The grandpa is pointing to a mountain
Der Opa zeigt für einen Berg
The granpa is pointing for a mountain
Der Uhu sucht nach einer Maus
The owl is looking for a mouse
Der Uhu sucht von einer Maus
The owl is searching from a mouse

20 In the English translations I tried to preserve the original structure of the German sentences as close as possible. In some cases, this could have resulted in unusual sentence structures or meanings in English.

Der Affe träumt von einer Banane
The monkey is dreaming of a banana
Der Affe träumt zu einer Banane
The monkey is dreaming to a banana
Der Bäcker fragt nach einem Apfel
The baker is asking for an apple
Der Bäcker fragt mit einem Apfel
The baker is asking with an apple
Das Schaf schimpft mit einer Ziege
The sheep is scolding a goat
Das Schaf schimpft von einer Ziege
The sheep is scolding from a goat
Der Hase zeigt auf einen Käfer
The rabbit is pointing at a beetle
Der Hase zeigt an einen Käfer
The rabbit is pointing on a beetle
Der Bär schimpft mit einer Biene
The bear is scolding a bee
Der Bär schimpft in einer Biene
The bear is scolding in a bee
Das Kind hört auf einen Lehrer
The child is listening to a teacher
Das Kind hört um einen Lehrer
The child is listening around a teacher
Der Gärtner sieht nach einer Blume
The gardener is looking for a flower
Der Gärtner sieht an einer Blume
The gardener is looking to a flower
Der Junge ruft nach einer Ratte
The boy is calling for a rat
Der Junge ruft von einer Ratte
The boy is calling from a rat
Der Hamster sucht nach einer Blume
The hamster is searching for a flower
Der Hamster sucht von einer Blume
The hamster is searching from a flower
Die Ente fragt nach einer Mütze

The duck is asking for a hat
Die Ente fragt von einer Mütze
The duck is asking from a hat
Der Löwe träumt von einer Katze
The lion is dreaming of a cat
Der Löwe träumt zu einer Katze
The lion is dreaming to a cat
Der Lehrer weiß von einer Geschichte
The teacher knows about a story
Der Lehrer weiß auf einer Geschichte
The teacher knows on a story
Die Tante hört von einer Freundin
The aunt hears from a friend
Die Tante hört aus einer Freundin
The aunt hears out of a friend
Der Bauer schimpft mit einem Hund
The farmer is scolding a dog
Der Bauer schimpft nach einem Hund
The farmer is scolding after a dog
Der Lehrer beginnt mit einer Rede
The teacher starts with a speech
Der Lehrer beginnt von einer Rede
The teacher starts from a speech
Der Angler glaubt an einen Fisch
The fisherman believes in a fish
Der Angler glaubt vor einen Fisch
The fisherman believes from a fish
Das Pferd denkt an einen Apfel
The horse is thinking about an apple
Das Pferd denkt um einen Apfel
The horse is thinking around an apple
Der Apfel passt zu einem Salat
The apple goes well with a salad
Der Apfel passt von einem Salat
The apple goes well from a salad
Die Schlange kämpft für einen Hasen
The snake is fighting for a rabbit

Die Schlange kämpft an einen Hasen
The snake is fighting to a rabbit
Die Mutter stimmt für eine Lehrerin
The mother is agreeing with a teacher
Die Mutter stimmt an eine Lehrerin
The mother is agreeing to a teacher
Der Hund schützt vor einem Dieb
The dog is protecting from a thief
Der Hund schützt auf einem Dieb
The dog is protecting on a thief
Die Maus denkt an einen Käse
The mouse is thinking about cheese
Die Maus denkt für einen Käse
The mouse is thinking for cheese
Die Lehrerin beginnt mit einem Lied
The teacher starts with a song
Die Lehrerin beginnt auf einem Lied
The teacher starts on a song
Die Katze fragt nach einer Maus
The cat is asking for a mouse
Die Katze fragt zu einer Maus
The cat is asking to a mouse
Der Schwan träumt von einem See
The swan is dreaming of a lake
Der Schwan träumt mit einem See
The swan is dreaming with a lake
Der Hase hofft auf einen Salat
The rabbit is hoping for a salad
Der Hase hofft für einen Salat
The rabbit is hoping on a salad
Die Maus lebt von einem Käse
The mouse lives on cheese
Die Maus lebt zu einem Käse
The mouse lives to cheese
Die Katze hört von einem Hund
The cat hears from a dog
Die Katze hört bei einem Hund

The cat hears at a dog
Die Löwin denkt an eine Katze
The lion is thinking of a cat
Die Löwin denkt um eine Katze
The lion is thinking around a cat
Die Blume passt zu einem Kleid
The flower suits a dress
Die Blume passt bei einem Kleid
The flower suits at a dress
Der Apfel hängt an einem Baum
The apple is hanging on a tree
Der Apfel hängt nach einem Baum
The apple is hanging after a tree
Das Küken hört auf einen Vogel
The chick is listening to a bird
Das Küken hört um einen Vogel
The chick is listening around a bird
Der Junge stimmt für einen Hund
The boy is voting for a dog
Der Junge stimmt auf einen Hund
The boy is voting on a dog
Die Eule träumt von einer Nuss
The owl is dreaming of a nut
Die Eule träumt aus einer Nuss
The owl is dreaming from a nut
Die Katze denkt an einen Kuchen
The cat is thinking of a cake
Die Katze denkt um einen Kuchen
The cat is thinking around a cake
Der Hund zeigt auf eine Katze
The dog is pointing at a cat
Der Hund zeigt um eine Katze
The dog is pointing around a cat
Das Mädchen sorgt für eine Puppe
The girl takes care of a doll
Das Mädchen sorgt in eine Puppe
The girl takes care in a doll

Die Tochter sorgt für einen Hund
The daughter takes care of a dog
Die Tochter sorgt an einen Hund
The daughter takes care on a dog
Die Oma kauft den Salat auf einem Markt
The grandma is buying salad on a market
Die Oma kauft den Salat mit einem Markt
The grandma is buying salad with a market
Die Ameise küsst den Käfer auf einer Blume
The ant is kissing the beetle on a flower
Die Ameise küsst den Käfer zu einer Blume
The ant is kissing the beetle to a flower
Der Mann trägt das Paket in einer Tasche
The man is carrying the package in a bag
Der Mann trägt das Paket bei einer Tasche
The man is carrying the package at a bag
Das Mädchen wirft den Stein zu einem Brunnen
The girl is throwing the stone to a well
Das Mädchen wirft den Stein mit einem Brunnen
The girl is throwing the stone with a well
Der Hund zieht die Katze in einen Teich
The dog is pulling the cat into a pond
Der Hund zieht die Katze für einen Teich
The dog is pulling the cat for a pond
Der Junge kneift das Mädchen auf einer Schaukel
The buy is pinching the girl on a swing
Der Junge kneift das Mädchen mit einer Schaukel
The boy is pinching the girl with a swing
Der Frosch grüßt die Schnecke von einem Freund
The frog sends the snail regards from a friend
Der Frosch grüßt die Schnecke zu einem Freund
The frog sends the snail regards to a friend
Das Mädchen tritt den Ball auf einer Wiese
The girl is kicking the ball on a meadow
Das Mädchen tritt den Ball mit einer Wiese
The girl is kicking the ball with a meadow
Die Oma hält die Katze auf einem Arm

The grandma is holding the cat on an arm
Die Oma hält die Katze nach einem Arm
The grandma is holding the cat after an arm
Die Tochter küsst die Mama auf eine Wange
The daughter is kissing the mother on a cheek
Die Tochter küsst die Mama für eine Wange
The daughter is kissing the mother for a cheek
Der Bär klaut den Honig aus einem Nest
The bear is stealing the honey out of a nest
Der Bär klaut den Honig zu einem Nest
The bear is stealing the honey to a nest
Die Maus kneift die Katze in eine Pfote
The mouse is pinching the cat on a paw
Die Maus kneift die Katze vor eine Pfote
The mouse is pinching the cat for a paw
Der Lehrer pflückt die Pflaume in einem Garten
The teacher is picking the plums in a garden
Der Lehrer pflückt die Pflaume mit einem Garten
The teacher is picking the plums with a garden
Die Dame grüßt den Mann auf einer Bank
The lady is greeting the mean on a bench
Die Dame grüßt den Mann zu einer Bank
The lady is greeting the man to a bench
Das Huhn wiegt das Ei in einem Stall
The chicken is weighing the egg in a stall
Das Huhn wiegt das Ei zu einem Stall
The chicken is weighing the egg to a stall
Die Ziege tritt das Schaf mit einem Bein
The goat is kicking the sheep with a leg
Die Ziege tritt das Schaf in einem Bein
The goat is kicking the sheep in a leg
Der Freund drückt die Klingel mit einem Finger
The friend is pressing the bell with a finger
Der Freund drückt die Klingel in einem Finger
The friend is pressing the bell in a finger
Das Kind trägt die Maus in einer Hand
The child is carrying the mouse in a hand

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Das Kind trägt die Maus nach einer Hand
The child is carrying the mouse after a hand
Die Tante wirft die Maus aus einem Haus
The aunt is throwing the mouse out of the house
Die Tante wirft die Maus mit einem Haus
The aunt is throwing the mouse with a house
Der Jäger hält die Zwiebel in einem Tuch
The hunter is holding the onions in a cloth
Der Jäger hält die Zwiebel zu einem Tuch
The hunter is holding the onions to a cloth
Der Affe wirft die Banane zu einem Freund
The monkey is throwing the banana to a friend
Der Affe wirft die Banane an einem Freund
The monkey is throwing the banana on a friend
Der Hase trifft den Igel nach einer Woche
The rabbit meets the hedgehog after a week
Der Hase trifft den Igel bei einer Woche
The rabbit meets the hedgehog at a week
Der Igel pflückt die Blume bei einem See
The hedgehog is picking the flower at a lake
Der Igel pflückt die Blume mit einem See
The hedgehog is picking the flower with a lake
Das Mädchen öffnet das Geschenk nach einer Sekunde
The girl opens the gift after a second
Das Mädchen öffnet das Geschenk auf einer Sekunde
The girl opens the gift on a second
Die Katze öffnet die Tür mit einer Pfote
The cat is opening the door with a paw
Die Katze öffnet die Tür in einer Pfote
The cat is opening the door with a paw
Die Giraffe trifft das Zebra vor einem Haus
The giraffe is meeting the zebra in front of a house
Die Giraffe trifft das Zebra mit einem Haus
The giraffe is meeting the zebra with a house
Der Junge trifft das Mädchen nach einem Monat
The boy meets the girl after a month
Der Junge trifft das Mädchen auf einem Monat

The boy meets the girl on a month
Das Mädchen kauft das Bonbon bei einem Händler
The girl is buying the candy from a dealer
Das Mädchen kauft das Bonbon zu einem Händler
The girl is buying the candy to a dealer
Die Maus füttert die Kuh vor einem Stall
The mouse is feeding the cow in front of a stall
Die Maus füttert die Kuh zu einem Stall
The mouse is feeding the cow to a stall
Der Lehrer kauft das Buch nach einer Woche
The teacher buys the book after a week
Der Lehrer kauft das Buch aus einer Woche
The teacher buys the book from a week
Der Affe fährt das Fahrrad um einen See
The monkey is riding the bike around a lake
Der Affe fährt das Fahrrad für einen See
The monkey is riding the bike for a lake
Der Papa trägt den Hund bei einem Ausflug
The father is taking the dog on a trip
Der Papa trägt den Hund mit einem Ausflug
The father is taking the dog with a trip
Der Tiger trifft den Löwen bei einem Baum
The tiger is meeting the lion at a tree
Der Tiger trifft den Löwen nach einem Baum
The tiger is meeting the lion after a tree
Der Junge pflückt die Äpfel von einem Nachbarn
The boy is picking the apples from a neighbor
Der Junge pflückt die Äpfel zu einem Nachbarn
The boy is picking the apples to a neighbor
Die Oma hält den Jungen an einer Hand
The grandma is holding the boy on a hand
Die Oma hält den Jungen von einer Hand
The grandma is holding the boy from a hand
Die Ente zieht das Huhn an einer Feder
The duck is pulling the chicken on a feather
Die Ente zieht das Huhn nach einer Feder
The duck is pulling the chicken after a feather

Der Storch trifft den Fuchs bei einem Baum
The crane is meeting the fox at a tree
Der Storch trifft den Fuchs nach einem Baum
The crane is meeting the fox after a tree
Das Kind zieht den Vater an einem Arm
The child is pulling the father by an arm
Das Kind zieht den Vater auf einem Arm
The child is pulling the father on an arm
Die Freundin öffnet das Schloss mit einem Schlüssel
The friend is opening the castle with a key
Die Freundin öffnet das Schloss aus einem Schlüssel
The friend is opening the castle from a key
Die Maus zieht die Katze an einem Ohr
The mouse is pulling the cat by an ear
Die Maus zieht die Katze vor einem Ohr
The mouse is pulling the cat for an ear
Der Vater misst das Kind mit einem Lineal
The father is measuring the child with a ruler
Der Vater misst das Kind nach einem Lineal
The father is measuring the child after a ruler

Control sentences

Der Hund gibt dem Prinzen einen Stock
The dog is giving the prince a stick
Der Hund gibt dem Prinzen einen Mond
The dog is giving the prince a moon
Der Opa gibt der Mutter eine Tasche
The grandpa is giving the mother a bag
Der Opa gibt der Mutter eine Ecke
The grandpa is giving the mother a corner
Die Bäckerin gibt der Oma eine Torte
The baker is giving the grandma a cake
Die Bäckerin gibt der Oma eine Stute
The baker is giving the grandma a mare
Der Vater gibt der Mama einen Tee
The father is giving the mother tea

Der Vater gibt der Mama einen Bach
The father is giving the mother a brook
Die Löwin gibt dem Kater einen Vogel
The lion is giving the cat a bird
Die Löwin gibt dem Kater einen Keller
The lion is giving the cat a cellar
Die Mama gibt der Lehrerin ein Spiel
The mother is giving the teacher a game
Die Mama gibt der Lehrerin ein Loch
The mother is giving the teacher a hole
Die Giraffe gibt dem Hamster ein Rad
The giraffe is giving the hamster a bike
Die Giraffe gibt dem Hamster ein Feld
The giraffe is giving the hamster a field
Die Königin gibt der Bäckerin eine Küche
The queen is giving the baker a kitchen
Die Königin gibt der Bäckerin eine Erde
The queen is giving the baker an earth
Das Mädchen gibt dem Papa ein Bild
The girl is giving the father a picture
Das Mädchen gibt dem Papa ein Meer
The girl is giving the father a see
Der Vogel gibt dem Schwein eine Blume
The bird is giving the pig a flower
Der Vogel gibt dem Schwein eine Rüstung
The bird is giving the pig an armor
Die Köchin kauft der Maus einen Ball
The chef is buying the mouse a ball
Die Köchin kauft der Maus einen See
The chef is buying the mouse a lake
Der Koch kauft der Köchin einen Löffel
The chef is buying the cook a spoon
Der Koch kauft der Köchin einen Riesen
The chef is buying the cook a giant
Der Bruder kauft der Prinzessin einen Mantel
The brother is buying the princess a coat
Der Bruder kauft der Prinzessin einen Bauer

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The brother is buying the princess a farmer
Die Prinzessin kauft der Polizistin ein Bild
The princess is buying the policewoman a picture
Die Prinzessin kauft der Polizistin ein Bein
The princess in buying the policewoman a lag
Der Onkel kauft dem Küken einen Käfig
The uncle is buying the chick a cage
Der Onkel kauft dem Küken einen Magen
The uncle is buying the chick a stomach
Der Sohn kauft dem Vogel eine Stange
The son is buying the bird a pole
Der Sohn kauft dem Vogel eine Zeile
The son is buying the bird a line
Die Oma kauft dem Arzt einen Korb
The grandma is buying the doctor a basket
Die Oma kauft dem Arzt einen Park
The grandma is buying the doctor a park
Die Lehrerin kauft der Freundin ein Essen
The teacher is buying the friend food
Die Lehrerin kauft der Freundin ein Gedicht
The teacher is buying the friend a poem
Die Polizistin kauft dem Bauer einen Schuppen
The policewoman is buying the farmer a shed
Die Polizistin kauft dem Bauer einen Laden
The policewoman is buying the farmer a shop
Die Tante kauft dem Fisch ein Glas
The aunt is buying the fish a glass
Die Tante kauft dem Fisch ein Pony
The aunt is buying the fish a pony
Das Gespenst kauft dem Affen eine Kerze
The ghost is buying the monkey a candle
Das Gespenst kauft dem Affen eine Backe
The ghost is buying the monkey a cheek
Der Arzt kauft der Löwin ein Rad
The doctor is buying the lion a bike
Der Arzt kauft der Löwin ein Feld
The doctor is buying the lion a field

Die Maus schenkt der Katze einen Käse
The mouse is giving the cat cheese
Die Maus schenkt der Katze einen Teppich
The mouse is giving the cat a carpet
Das Pony schenkt dem Hasen ein Brot
The pony is giving the rabbit bread
Das Pony schenkt dem Hasen ein Knie
The pony is giving the rabbit a knee
Der Frosch schenkt dem Koch eine Schnecke
The frog is giving the chef a snail
Der Frosch schenkt dem Koch eine Wüste
The frog is giving the chef a desert
Die Tochter gibt der Freundin ein Spiel
The daughter is giving the friend a game
Die Tochter gibt der Freundin ein Loch
The daughter is giving the friend a hole
Die Schwester gibt der Tante einen Ball
The sister is giving the aunt a ball
Die Schwester gibt der Tante einen Berg
The sister is giving the aunt a mountain
Die Tante schenkt dem Neffen eine Blume
The aunt is giving the nephew a flower
Die Tante schenkt dem Neffen eine Lippe
The aunt is giving the nephew a lip
Der Löwe gibt dem Trainer eine Pfote
The lion is giving the coach a paw
Der Löwe gibt dem Trainer eine Brille
The lion is giving the coach glasses
Die Bäuerin kauft dem Knecht eine Hose
The farmer is buying the servant trousers
Die Bäuerin kauft dem Knecht eine Träne
The framer is buying the servant a tear
Die Frau kauft dem Jungen eine Mütze
The woman is buying the boy a hat
Die Frau kauft dem Jungen eine Brücke
The woman is buying the boy a stream
Der Mann gibt dem Freund einen Schlüssel

The man is giving the friend a key
Der Mann gibt dem Freund einen Lehrer
The man is giving the friend a teacher
Der Pfarrer gibt der Dame einen Tee
The pastor is serving the lady tee
Der Pfarrer gibt der Dame einen Müll
The pastor is serving the lady garbage
Der Kellner gibt der Mutter eine Karte
The waiter is giving the mother a card
Der Kellner gibt der Mutter eine Träne
The waiter is giving the mother a tear
Die Taube gibt dem Küken ein Blatt
The dove is giving the chick a leaf
Die Taube gibt dem Küken ein Tor
The dove is giving the chick a gate
Der Sänger schenkt dem Kellner eine Blume
The singer is giving the waiter a flower
Der Sänger schenkt dem Kellner einen Flügel
The singer is giving the waiter a piano
Der Maler schenkt der Sängerin ein Bild
The painter is giving the singer a picture
Der Maler schenkt der Sängerin ein Bein
The painter is giving the singer a lag
Der Fahrer schenkt dem Maler eine Jacke
The driver is giving the painter a coat
Der Fahrer schenkt dem Maler eine Welle
The driver is giving the painter a
Die Sängerin kauft dem Jungen ein Eis
The singer is buying the boy ice-cream
Die Sängerin kauft dem Jungen ein Loch
The singer is buying the boy a hole
Die Oma kauft dem Pfarrer eine Suppe
The grandma is buying the pastor soup
Die Oma kauft dem Pfarrer eine Schnauze
The grandma is buying the pastor a muzzle
Der Fisch gibt dem Frosch einen Teich
The fish is giving the frog a pond

Der Fisch gibt dem Frosch einen Ort
The fish is giving the frog a location
Die Hexe kauft dem Onkel eine Mütze
The witch is buying the uncle a hat
Die Hexe kauft dem Onkel eine Brücke
The witch is buying the uncle a bridge

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Appendix B: full statistical models of the analyses used in Chapter 5.

LMM for the preposition in LexP sentences

Table B-2. Lexical preposition time window 100 – 250 ms.

Linear mixed model fit by REML

REML criterion at convergence: 336414.2

Scaled residuals:

Min	1Q	Median	3Q	Max
-9.0417	-0.6069	-0.0009	0.6044	6.4902

Random effects:

Groups	Name	Variance	Std.Dev.
sent.id	(Intercept)	1.311	1.145
Subject	(Intercept)	1.888	1.374
Residual		84.949	9.217

Number of obs: 46176, groups: sent.id, 41; Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	5.751e-01	3.111e-01	5.400e+01	1.849	0.07000	.
congruity_congruent	2.453e-01	4.325e-02	4.614e+04	5.673	1.41e-08	***
laterality_central	-7.093e-02	6.067e-02	4.610e+04	-1.169	0.24235	
laterality_left	1.794e-01	6.067e-02	4.610e+04	2.957	0.00311	**
anteriority_anterior	-8.320e-02	4.290e-02	4.610e+04	-1.939	0.05245	.
congruity_congruent:laterality_central	7.596e-02	6.067e-02	4.610e+04	1.252	0.21057	
congruity_congruent:laterality_left	-1.705e-02	6.067e-02	4.610e+04	-0.281	0.77867	
congruity_congruent:anteriority_anterior	-8.060e-03	4.290e-02	4.610e+04	-0.188	0.85098	
laterality_central:anteriority_anterior	7.333e-04	6.067e-02	4.610e+04	0.012	0.99036	
laterality_left:anteriority_anterior	-3.395e-03	6.067e-02	4.610e+04	-0.056	0.95538	
congruity_congruent:laterality_central:anteriority_anterior	-9.359e-03	6.067e-02	4.610e+04	-0.154	0.87741	
congruity_congruent:laterality_left:anteriority_anterior	-2.256e-02	6.067e-02	4.610e+04	-0.372	0.70996	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table B-2a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
congruity	2733.54	2733.54	1	46142	32.179	1.415E-08	***
laterality	753.58	376.79	2	46095	4.436	0.01185	*
anteriority	319.53	319.53	1	46095	3.761	0.05245	.
congruity:laterality	146.64	73.32	2	46095	0.863	0.42187	
congruity:anteriority	3.00	3.00	1	46095	0.035	0.85098	
laterality:anteriority	0.29	0.15	2	46095	0.002	0.99827	
congruity:laterality:anteriority	24.86	12.43	2	46095	0.146	0.86388	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table B-3. Lexical preposition time window 300 – 550 ms

Linear mixed model fit by REML

REML criterion at convergence: 349127.5

```
Scaled residuals:
    Min      1Q  Median      3Q     Max
-6.7512 -0.6055  0.0075  0.6012 11.3361
Random effects:
 Groups   Name        Variance Std.Dev.
 sent.id  (Intercept)   1.782   1.335
 Subject  (Intercept)   2.531   1.591
 Residual             111.878  10.577
Number of obs: 46176, groups:  sent.id, 41; Subject, 30
```

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	2.470e-01	3.610e-01	5.400e+01	0.684	0.49672	
congruity_congruent	3.665e-01	4.963e-02	4.614e+04	7.384	1.57e-13	***
laterality_central	-1.426e-02	6.962e-02	4.610e+04	-0.205	0.83771	
laterality_left	1.466e-01	6.962e-02	4.610e+04	2.106	0.03523	*

table continues

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	Estimate	Std.Error	df	t-value	Pr(>|t|)	
anteriority_anterior	-1.180e-01	4.923e-02	4.610e+04	-2.398	0.01651	*
congruity_congruent:laterality_central	3.786e-02	6.962e-02	4.610e+04	0.544	0.58658	
congruity_congruent:laterality_left	-4.260e-02	6.962e-02	4.610e+04	-0.612	0.54063	
congruity_congruent:anteriority_anterior	-1.395e-01	4.923e-02	4.610e+04	-2.833	0.00461	**
laterality_central:anteriority_anterior	4.657e-02	6.962e-02	4.610e+04	0.669	0.50357	
laterality_left:anteriority_anterior	-6.319e-02	6.962e-02	4.610e+04	-0.908	0.36410	
congruity_congruent:laterality_central:anteriority_anterior	-2.182e-02	6.962e-02	4.610e+04	-0.313	0.75403	
congruity_congruent:laterality_left:anteriority_anterior	-1.684e-02	6.962e-02	4.610e+04	-0.242	0.80894	

Table B-3a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
congruity	6099.5	6099.5	1	46142	54.519	1.565E-13	***
laterality	603.3	301.7	2	46095	2.696	0.067454	.
anteriority	643.1	643.1	1	46095	5.748	0.016511	*
congruity:laterality	50.3	25.2	2	46095	0.225	0.798586	
congruity:anteriority	897.9	897.9	1	46095	8.025	0.004614	**
laterality:anteriority	99.1	49.5	2	46095	0.443	0.642296	
congruity:laterality:anteriority	34.7	17.3	2	46095	0.155	0.856466	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table B-4. Lexical preposition time window 550 – 1000 ms.

Linear mixed model fit by REML

REML criterion at convergence: 359297.7

Scaled residuals:

Min	1Q	Median	3Q	Max
-10.0116	-0.5856	-0.0015	0.5897	13.0748

Random effects:

Groups	Name	Variance	Std.Dev.
sent.id	(Intercept)	2.652	1.628
Subject	(Intercept)	4.029	2.007
Residual		139.409	11.807

Number of obs: 46176, groups: sent.id, 41; Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	7.338e-02	4.495e-01	5.300e+01	0.163	0.871	
congruity_congruent	4.411e-02	5.541e-02	4.614e+04	0.796	0.426	
laterality_central	9.467e-02	7.772e-02	4.610e+04	1.218	0.223	
laterality_left	7.976e-03	7.772e-02	4.610e+04	0.103	0.918	
anteriority_anterior	-6.023e-01	5.496e-02	4.610e+04	-10.959	<2e-16	***
congruity_congruent:laterality_central	5.748e-02	7.772e-02	4.610e+04	0.740	0.460	
congruity_congruent:laterality_left	-8.078e-02	7.772e-02	4.610e+04	-1.039	0.299	
congruity_congruent:anteriority_anterior	1.159e-02	5.496e-02	4.610e+04	0.211	0.833	
laterality_central:anteriority_anterior	8.217e-02	7.772e-02	4.610e+04	1.057	0.290	
laterality_left:anteriority_anterior	-1.093e-01	7.772e-02	4.610e+04	-1.407	0.159	
congruity_congruent:laterality_central:anteriority_anterior	-1.752e-02	7.772e-02	4.610e+04	-0.225	0.822	
congruity_congruent:laterality_left:anteriority_anterior	-6.766e-03	7.772e-02	4.610e+04	-0.087	0.931	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

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Table B-4a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
congruity	88.3	88.3	1	46140	0.634	0.4260	
laterality	301.0	150.5	2	46095	1.080	0.3397	
anteriority	16744.3	16744.3	1	46095	120.109	<2e-16	***
congruity:laterality	159.6	79.8	2	46095	0.572	0.5642	
congruity:anteriority	6.2	6.2	1	46095	0.044	0.8329	
laterality:anteriority	299.2	149.6	2	46095	1.073	0.3420	
congruity:laterality:anteriority	14.5	7.3	2	46095	0.052	0.9493	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Noun in LexP sentences

Table B-5. Noun in LexP sentences time window 300 – 550 ms.

Linear mixed model fit by REML

REML criterion at convergence: 371468.8

Scaled residuals:
Min 1Q Median 3Q Max
-9.9277 -0.5939 -0.0048 0.5922 12.7209
Random effects:
Groups Name Variance Std.Dev.
sent.id (Intercept) 4.812 2.194
Subject (Intercept) 5.972 2.444
Residual 181.400 13.468
Number of obs: 46176, groups: sent.id, 41; Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	-4.761e-02	5.660e-01	5.700e+01	-0.084	0.93326	
congruity_congruent	4.851e-01	6.312e-02	4.613e+04	7.685	1.55e-14	***
laterality_central	2.508e-01	8.866e-02	4.610e+04	2.829	0.00467	**

table continues

	Estimate	Std.Error	df	t-value	Pr(>|t|)	
laterality_left	-1.552e-02	8.866e-02	4.610e+04	-0.175	0.86106	
anteriority_anterior	-6.694e-01	6.269e-02	4.610e+04	-10.678	<2e-16	***
congruity_congruent:laterality_central	1.487e-01	8.866e-02	4.610e+04	1.677	0.09352	.
congruity_congruent:laterality_left	-1.312e-01	8.866e-02	4.610e+04	-1.480	0.13882	
congruity_congruent:anteriority_anterior	8.231e-02	6.269e-02	4.610e+04	1.313	0.18919	
laterality_central:anteriority_anterior	1.891e-01	8.866e-02	4.610e+04	2.133	0.03292	*
laterality_left:anteriority_anterior	-1.861e-01	8.866e-02	4.610e+04	-2.099	0.03582	*
congruity_congruent:laterality_central:anteriority_anterior	1.813e-03	8.866e-02	4.610e+04	0.020	0.98368	
congruity_congruent:laterality_left:anteriority_anterior	-1.150e-02	8.866e-02	4.610e+04	-0.130	0.89677	

Table B-5a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
congruity	10712.1	10712.1	1	46131	59.052	1.565e-14	***
laterality	1823.5	911.7	2	46095	5.026	0.006568	**
anteriority	20681.9	20681.9	1	46095	114.012	<2.2e-16	***
congruity:laterality	609.8	304.9	2	46095	1.681	0.186218	
congruity:anteriority	312.7	312.7	1	46095	1.724	0.189188	
laterality:anteriority	1083.2	541.6	2	46095	2.986	0.050509	.
congruity:laterality:anteriority	3.5	1.8	2	46095	0.010	0.990316	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

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Table B-6. Noun in LexP sentences time window 550 – 1000 ms.

Linear mixed model fit by REML

REML criterion at convergence: 377212.1

Scaled residuals:

Min	1Q	Median	3Q	Max
-9.1024	-0.6044	0.0025	0.5937	11.4853

Random effects:

Groups	Name	Variance	Std.Dev.
sent.id	(Intercept)	2.858	1.691
Subject	(Intercept)	11.653	3.414
Residual		205.473	14.334

Number of obs: 46176, groups: sent.id, 41; Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	3.710e+00	6.802e-01	3.900e+01	5.455	2.91e-06	***
congruity_congruent	-3.856e-01	6.717e-02	4.614e+04	-5.740	9.53e-09	***
laterality_central	9.432e-01	9.436e-02	4.610e+04	9.996	<2e-16	***
laterality_left	-5.021e-01	9.436e-02	4.610e+04	-5.322	1.03e-07	***
anteriority_anterior	-1.196e+00	6.672e-02	4.610e+04	-17.920	<2e-16	***
congruity_congruent:laterality_central	-3.325e-02	9.436e-02	4.610e+04	-0.352	0.72457	
congruity_congruent:laterality_left	-4.180e-02	9.436e-02	4.610e+04	-0.443	0.65776	
congruity_congruent:anteriority_anterior	3.133e-01	6.672e-02	4.610e+04	4.696	2.66e-06	***
laterality_central:anteriority_anterior	2.869e-01	9.436e-02	4.610e+04	3.041	0.00236	**
laterality_left:anteriority_anterior	-2.808e-01	9.436e-02	4.610e+04	-2.976	0.00292	**
congruity_congruent:laterality_central:anteriority_anterior	-1.093e-01	9.436e-02	4.610e+04	-1.158	0.24682	
congruity_congruent:laterality_left:anteriority_anterior	2.741e-02	9.436e-02	4.610e+04	0.291	0.77141	

Table B-6a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	Sum Sq	Mean Sq	NumDF	DenDF	F.value	Pr(>F)	
congruity	6770	6770	1	46138	32.95	9.527e-09	***
laterality	20561	10281	2	46095	50.03	< 2.2e-16	***
anteriority	65984	65984	1	46095	321.13	< 2.2e-16	***
congruity:laterality	131	65	2	46095	0.32	0.727838	
congruity:anteriority	4531	4531	1	46095	22.05	2.661e-06	***
laterality:anteriority	2480	1240	2	46095	6.03	0.002396	**
congruity:laterality:anteriority	298	149	2	46095	0.73	0.483781	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Preposition in SubP sentences

Table B-7. Preposition in SubP sentences in the time window 300 – 550 ms.

Linear mixed model fit by REML

REML criterion at convergence: 367043.6

Scaled residuals:

Min	1Q	Median	3Q	Max
-14.8922	-0.6129	-0.0151	0.5793	9.9675

Random effects:

Groups	Name	Variance	Std.Dev.
sent.id	(Intercept)	4.120	2.030
Subject	(Intercept)	6.509	2.551
Residual		175.443	13.245

Number of obs: 45816, groups: sent.id, 41; Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	2.522e-02	5.669e-01	5.300e+01	0.044	0.9647	
congruity_congruent	-1.053e+00	6.254e-02	4.578e+04	-16.836	<2e-16	***
laterality_central	4.925e-02	8.754e-02	4.574e+04	0.563	0.5737	

table continues

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	Estimate	Std.Error	df	t-value	Pr(>|t|)	
laterality_left	1.379e-01	8.754e-02	4.574e+04	1.575	0.1153	
anteriority_anterior	-1.114e+00	6.190e-02	4.574e+04	-17.996	<2e-16	***
congruity_congruent:laterality_central	-1.852e-01	8.754e-02	4.574e+04	-2.116	0.0344	*
congruity_congruent:laterality_left	6.646e-02	8.754e-02	4.574e+04	0.759	0.4477	
congruity_congruent:anteriority_anterior	3.087e-01	6.190e-02	4.574e+04	4.988	6.13e-07	***
laterality_central:anteriority_anterior	2.927e-02	8.754e-02	4.574e+04	0.334	0.7381	
laterality_left:anteriority_anterior	-3.172e-02	8.754e-02	4.574e+04	-0.362	0.7171	
congruity_congruent:laterality_central:anteriority_anterior	-5.629e-02	8.754e-02	4.574e+04	-0.643	0.5202	
congruity_congruent:laterality_left:anteriority_anterior	4.264e-03	8.754e-02	4.574e+04	0.049	0.9612	

Table B-7a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
congruity	49730	49730	1	45779	283.45	<2.2e-16	***
laterality	862	431	2	45735	2.46	0.08584	.
anteriority	56815	56815	1	45735	323.84	<2.2e-16	***
congruity:laterality	806	403	2	45735	2.30	0.10055	
congruity:anteriority	4365	4365	1	45735	24.88	6.131e-07	***
laterality:anteriority	29	14	2	45735	0.08	0.92192	
congruity:laterality:anteriority	90	45	2	45735	0.26	0.77382	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table B-8. Preposition in SubP sentences in the time window 550 – 1000 ms.

Linear mixed model fit by REML

REML criterion at convergence: 361627.3

Scaled residuals:

Min	1Q	Median	3Q	Max
-16.1979	-0.6116	-0.0057	0.5800	10.4279

Random effects:

Groups	Name	Variance	Std.Dev.
sent.id	(Intercept)	2.191	1.480
Subject	(Intercept)	4.351	2.086
Residual		140.258	11.843

Number of obs: 46440, groups: sent.id, 41; Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	3.898e-01	4.489e-01	4.900e+01	0.868	0.390	
congruity_congruent	-1.155e+00	5.518e-02	4.639e+04	-20.939	<2e-16	***
laterality_central	7.723e-02	7.772e-02	4.636e+04	0.994	0.320	
laterality_left	2.871e-02	7.772e-02	4.636e+04	0.369	0.712	
anteriority_anterior	-8.824e-01	5.496e-02	4.636e+04	-16.057	<2e-16	***
congruity_congruent:laterality_central	-1.909e-01	7.772e-02	4.636e+04	-2.456	0.014	*
congruity_congruent:laterality_left	8.604e-02	7.772e-02	4.636e+04	1.107	0.268	
congruity_congruent:anteriority_anterior	2.409e-01	5.496e-02	4.636e+04	4.383	1.18e-05	***
laterality_central:anteriority_anterior	1.201e-02	7.772e-02	4.636e+04	0.155	0.877	
laterality_left:anteriority_anterior	-4.003e-03	7.772e-02	4.636e+04	-0.052	0.959	

Table B-8a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
congruity	61493	61493	1	46387	438.43	<2.2e-16	***
laterality	279	139	2	46359	0.99	0.37017	
anteriority	36161	36161	1	46359	257.82	<2.2e-16	***
congruity:laterality	849	424	2	46359	3.03	0.04852	*
congruity:anteriority	2694	2694	1	46359	19.21	1.176e-05	***
laterality:anteriority	3	2	2	46359	0.01	0.98768	
congruity:laterality:anteriority	74	37	2	46359	0.26	0.76733	

Noun in SubP sentences

Table B-9. Noun in SubP sentences in the time window 550 – 1000 ms
Linear mixed model fit by REML

REML criterion at convergence: 373577.3

Scaled residuals:
Min 1Q Median 3Q Max
-13.7972 -0.6093 -0.0123 0.5918 11.0552
Random effects:
Groups Name Variance Std.Dev.
sent.id (Intercept) 3.99 1.998
Subject (Intercept) 9.83 3.135
Residual 202.34 14.225
Number of obs: 45816, groups: sent.id, 41; Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	2.787e+00	6.554e-01	4.500e+01	4.252	0.000104	***
congruity_congruent	-9.325e-01	6.716e-02	4.577e+04	-13.885	<2e-16	***
laterality_central	5.693e-01	9.401e-02	4.574e+04	6.056	1.40e-09	***

table continues

	Estimate	Std.Error	df	t-value	Pr(>|t|)	
laterality_left	-1.983e-01	9.401e-02	4.574e+04	-2.110	0.034896	*
anteriority_anterior	-1.508e+00	6.647e-02	4.574e+04	-22.680	<2e-16	***
congruity_congruent:laterality_central	-1.350e-01	9.401e-02	4.574e+04	-1.436	0.151022	
congruity_congruent:laterality_left	-1.385e-02	9.401e-02	4.574e+04	-0.147	0.882846	
congruity_congruent:anteriority_anterior	3.151e-01	6.647e-02	4.574e+04	4.741	2.13e-06	***
laterality_central:anteriority_anterior	1.633e-01	9.401e-02	4.574e+04	1.738	0.082300	.
laterality_left:anteriority_anterior	-1.277e-01	9.401e-02	4.574e+04	-1.358	0.174460	
congruity_congruent:laterality_central:anteriority_anterior	-6.749e-02	9.401e-02	4.574e+04	-0.718	0.472772	
congruity_congruent:laterality_left:anteriority_anterior	1.258e-02	9.401e-02	4.574e+04	0.134	0.893515	

Table B-9a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
congruity	39009	39009	1	45774	192.79	<2.2e-16	***
laterality	7649	3824	2	45735	18.90	6.231e-09	***
anteriority	104084	104084	1	45735	514.41	<2.2e-16	***
congruity:laterality	619	310	2	45735	1.53	0.2165	
congruity:anteriority	4548	4548	1	45735	22.48	2.133e-06	***
laterality:anteriority	675	338	2	45735	1.67	0.1884	
congruity:laterality:anteriority	118	59	2	45735	0.29	0.7471	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

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Difference waveform analyses

Table B-10. Analyses of the difference waveforms of lexical and subcategorized prepositions in the time window 100 – 250 ms relative to the prepositions.

Linear mixed model fit by REML

REML criterion at convergence: 264123.8

Scaled residuals:

Min	1Q	Median	3Q	Max
-7.5314	-0.6250	0.0038	0.6101	7.4769

Random effects:

Groups	Name	Variance	Std.Dev.
Subject	(Intercept)	1.065	1.032
Residual		84.972	9.218

Number of obs: 36264, groups: Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	8.293e-01	1.946e-01	2.900e+01	4.262	0.000197	***
sentence.type_lexP	1.972e-01	4.849e-02	3.624e+04	4.067	4.77e-05	***
laterality_central	-9.906e-03	6.846e-02	3.622e+04	-0.145	0.884950	
laterality_left	8.584e-02	6.846e-02	3.622e+04	1.254	0.209888	
anteriority_anterior	-7.325e-02	4.841e-02	3.622e+04	-1.513	0.130239	
sentence.type_lexP:laterality_central	6.068e-02	6.846e-02	3.622e+04	0.886	0.375394	
sentence.type_lexP:laterality_left	8.392e-02	6.846e-02	3.622e+04	1.226	0.220263	
sentence.type_lexP:anteriority_anterior	2.122e-02	4.841e-02	3.622e+04	0.438	0.661100	
laterality_central:anteriority_anterior	3.502e-02	6.846e-02	3.622e+04	0.512	0.608915	
laterality_left:anteriority_anterior	-4.021e-02	6.846e-02	3.622e+04	-0.587	0.556915	
sentence.type_lexP:laterality_central:anteriority_anterior	-1.055e-02	6.846e-02	3.622e+04	-0.154	0.877573	
sentence.type_lexP:laterality_left:anteriority_anterior	8.256e-03	6.846e-02	3.622e+04	0.121	0.904005	

Table B-10a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
sentence.type	1405.40	1405.40	1	36238	16.5396	4.774e-05	***
laterality	159.95	79.97	2	36223	0.9412	0.3902	
anteriority	194.57	194.57	1	36223	2.2898	0.1302	
sentence.type:laterality	382.38	191.19	2	36223	2.2501	0.1054	
sentence.type:anteriority	16.33	16.33	1	36223	0.1922	0.6611	
laterality:anteriority	34.70	17.35	2	36223	0.2042	0.8153	
sentence.type:laterality:anteriority	2.23	1.12	2	36223	0.0131	0.9870	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table B-11. Analyses of the difference waveforms of lexical and subcategorized prepositions in the time window 300 – 550 ms relative to the prepositions.

Linear mixed model fit by REML

REML criterion at convergence: 274857.2

Scaled residuals:
Min 1Q Median 3Q Max
-13.1621 -0.6059 -0.0020 0.6026 7.4440
Random effects:
Groups Name Variance Std.Dev.
Subject (Intercept) 1.975 1.405
Residual 114.223 10.688
Number of obs: 36264, groups: Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	7.530e-01	2.627e-01	2.900e+01	2.866	0.00765	**
sentence.type_lexP	1.268e-01	5.622e-02	3.623e+04	2.256	0.02410	*
laterality_central	1.671e-01	7.937e-02	3.622e+04	2.106	0.03522	*
laterality_left	1.882e-02	7.937e-02	3.622e+04	0.237	0.81261	
anteriority_anterior	-1.123e-01	5.612e-02	3.622e+04	-2.000	0.04546	*

table continues

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	Estimate	Std.Error	df	t-value	Pr(>|t|)
sentence.type_lexP:laterality_central	-7.506e-02	7.937e-02	3.622e+04	-0.946	0.34429
sentence.type_lexP:laterality_left	9.542e-02	7.937e-02	3.622e+04	1.202	0.22931
sentence.type_lexP:anteriority_anterior	-8.318e-02	5.612e-02	3.622e+04	-1.482	0.13834
laterality_central:anteriority_anterior	3.316e-02	7.937e-02	3.622e+04	0.418	0.67610
laterality_left:anteriority_anterior	-5.736e-02	7.937e-02	3.622e+04	-0.723	0.46989
sentence.type_lexP:laterality_central:anteriority_anterior	1.641e-02	7.937e-02	3.622e+04	0.207	0.83622
sentence.type_lexP:laterality_left:anteriority_anterior	-3.940e-02	7.937e-02	3.622e+04	-0.496	0.61962

Table B-11a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
sentence.type	581.11	581.11	1	36234	5.0875	0.02410	*
laterality	759.98	379.99	2	36223	3.3267	0.03592	*
anteriority	457.11	457.11	1	36223	4.0019	0.04546	*
sentence.type:laterality	183.17	91.58	2	36223	0.8018	0.44853	
sentence.type:anteriority	250.88	250.88	1	36223	2.1964	0.13834	
laterality:anteriority	60.14	30.07	2	36223	0.2633	0.76855	
sentence.type:laterality:anteriority	28.41	14.20	2	36223	0.1243	0.88307	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table B-12. Analyses of the difference waveforms of lexical and subcategorized prepositions in the time window 550 – 1000 ms relative to the prepositions.
Linear mixed model fit by REML

REML criterion at convergence: 282907.1
Scaled residuals: Min 1Q Median 3Q Max -15.7147 -0.6016 -0.0045 0.5933 10.5358

table continues

REML criterion at convergence: 282907.1

Random effects:

Groups	Name	Variance	Std.Dev.
Subject	(Intercept)	3.509	1.873
Residual		142.585	11.941

Number of obs: 36264, groups: Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	-1.933e-01	3.478e-01	2.900e+01	-0.556	0.582	
sentence.type_lexP	4.044e-01	6.282e-02	3.623e+04	6.438	1.23e-10	***
laterality_central	4.991e-02	8.868e-02	3.622e+04	0.563	0.574	
laterality_left	-3.482e-02	8.868e-02	3.622e+04	-0.393	0.695	
anteriority_anterior	-5.576e-01	6.270e-02	3.622e+04	-8.893	<2e-16	***
sentence.type_lexP:laterality_central	1.397e-01	8.868e-02	3.622e+04	1.575	0.115	
sentence.type_lexP:laterality_left	-6.644e-02	8.868e-02	3.622e+04	-0.749	0.454	
sentence.type_lexP:anteriority_anterior	3.368e-02	6.270e-02	3.622e+04	0.537	0.591	
laterality_central:anteriority_anterior	2.106e-02	8.868e-02	3.622e+04	0.237	0.812	
laterality_left:anteriority_anterior	-6.256e-02	8.868e-02	3.622e+04	-0.705	0.481	
sentence.type_lexP:laterality_central:anteriority_anterior	5.527e-02	8.868e-02	3.622e+04	0.623	0.533	
sentence.type_lexP:laterality_left:anteriority_anterior	-6.865e-02	8.868e-02	3.622e+04	-0.774	0.439	

Table B-12a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
sentence.type	5909.2	5909.2	1	36232	41.443	1.229e-10	***
laterality	47.5	23.8	2	36223	0.167	0.8465	
anteriority	11276.5	11276.5	1	36223	79.086	<2.2e-16	***
sentence.type:laterality	353.9	177.0	2	36223	1.241	0.2891	
sentence.type:anteriority	41.1	41.1	1	36223	0.288	0.5912	
laterality:anteriority	73.5	36.7	2	36223	0.258	0.7728	
sentence.type:laterality:anteriority	96.1	48.0	2	36223	0.337	0.7140	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

A

Table B-13. Analyses of the difference waveforms of nouns in LexP and SubP sentences in the time window 550 – 1000 ms relative to the nouns.

Linear mixed model fit by REML

REML criterion at convergence: 292222.8

Scaled residuals:

Min	1Q	Median	3Q	Max
-13.3098	-0.5916	-0.0149	0.5823	11.0289

Random effects:

Groups	Name	Variance	Std.Dev.
Subject	(Intercept)	6.881	2.623
Residual		209.924	14.489

Number of obs: 35688, groups: Subject, 30

Fixed effects:	Estimate	Std.Error	df	t-value	Pr(>|t|)	
(Intercept)	2.832e+00	4.851e-01	2.900e+01	5.839	2.47e-06	***
sentence.type_lexP	7.616e-01	7.683e-02	3.565e+04	9.912	<2e-16	***
laterality_central	7.315e-01	1.085e-01	3.565e+04	6.744	1.56e-11	***
laterality_left	-4.399e-01	1.085e-01	3.565e+04	-4.055	5.01e-05	***
anteriority_anterior	-1.021e+00	7.670e-02	3.565e+04	-13.314	<2e-16	***
sentence.type_lexP:laterality_central	2.363e-01	1.085e-01	3.565e+04	2.178	0.0294	*
sentence.type_lexP:laterality_left	-1.398e-01	1.085e-01	3.565e+04	-1.289	0.1975	
sentence.type_lexP:anteriority_anterior	1.124e-01	7.670e-02	3.565e+04	1.465	0.1430	
laterality_central:anteriority_anterior	1.596e-01	1.085e-01	3.565e+04	1.471	0.1413	
laterality_left:anteriority_anterior	-1.880e-01	1.085e-01	3.565e+04	-1.733	0.0830	.
sentence.type_lexP:laterality_central:anteriority_anterior	4.454e-02	1.085e-01	3.565e+04	0.411	0.6814	
sentence.type_lexP:laterality_left:anteriority_anterior	-7.651e-02	1.085e-01	3.565e+04	-0.705	0.4806	

Table B-13a. Analysis of Variance Table of type III with Satterthwaite approximation for degrees of freedom.

	SumSq	MeanSq	NumDF	DenDF	F.value	Pr(>F)	
sentence.type	20626	20626	1	35653	98.256	<2.2e-16	***
laterality	9679	4839	2	35647	23.053	9.881e-11	***
anteriority	37210	37210	1	35647	177.254	<2.2e-16	***
sentence.type:laterality	1007	504	2	35647	2.399	0.09087	.
sentence.type:anteriority	450	450	1	35647	2.146	0.14300	
laterality:anteriority	733	366	2	35647	1.746	0.17452	
sentence.type:laterality:anteriority	105	53	2	35647	0.251	0.77803	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

A

Appendix C: supplementary materials for the ERP study reported in Chapter 7

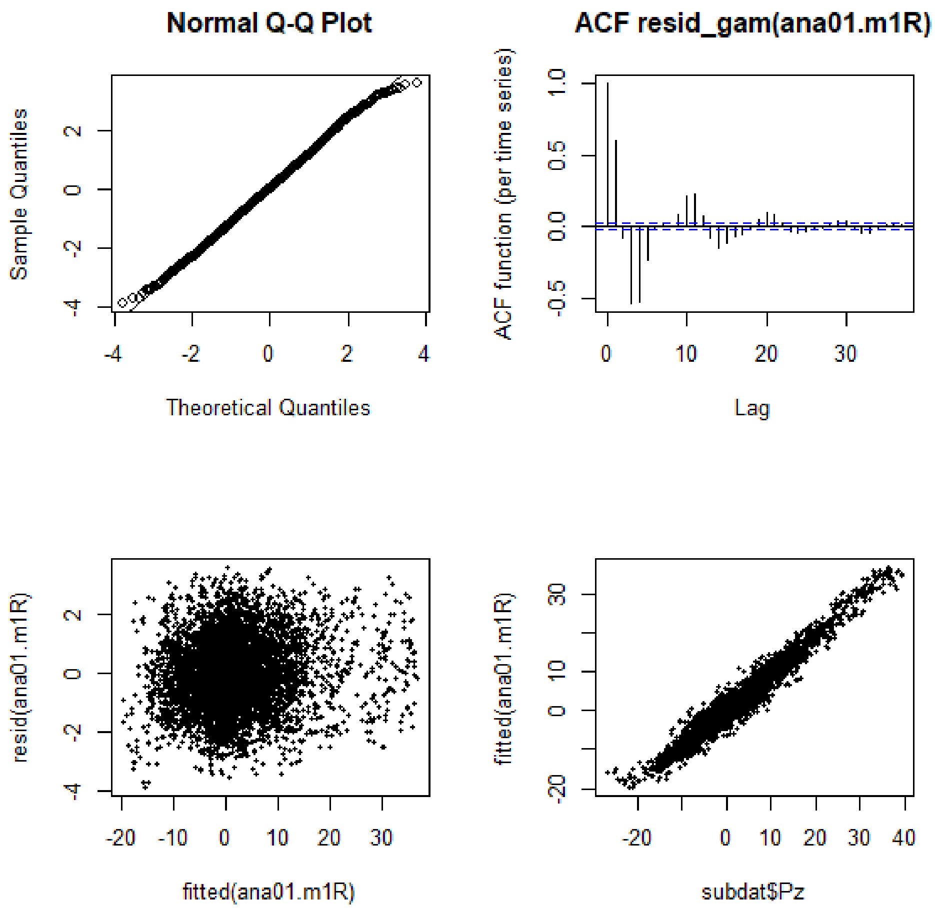
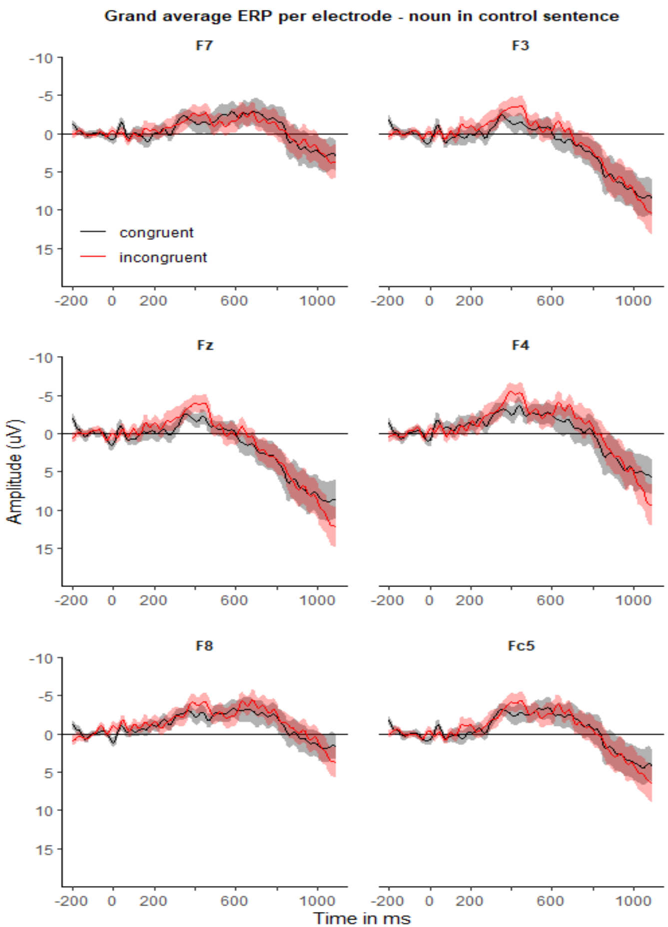
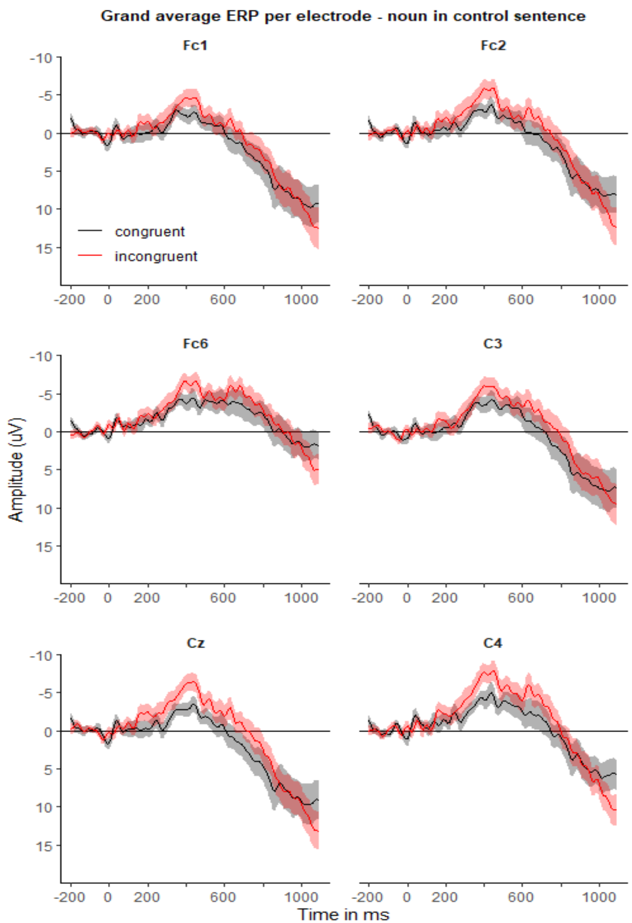


Figure C-1. Model checking plots for the model developed for control sentenc


Grand average ERP per electrode - noun in control sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Amplitude (uV)
Time in ms


Grand average ERP per electrode - noun in control sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Amplitude (uV)
Time in ms

A

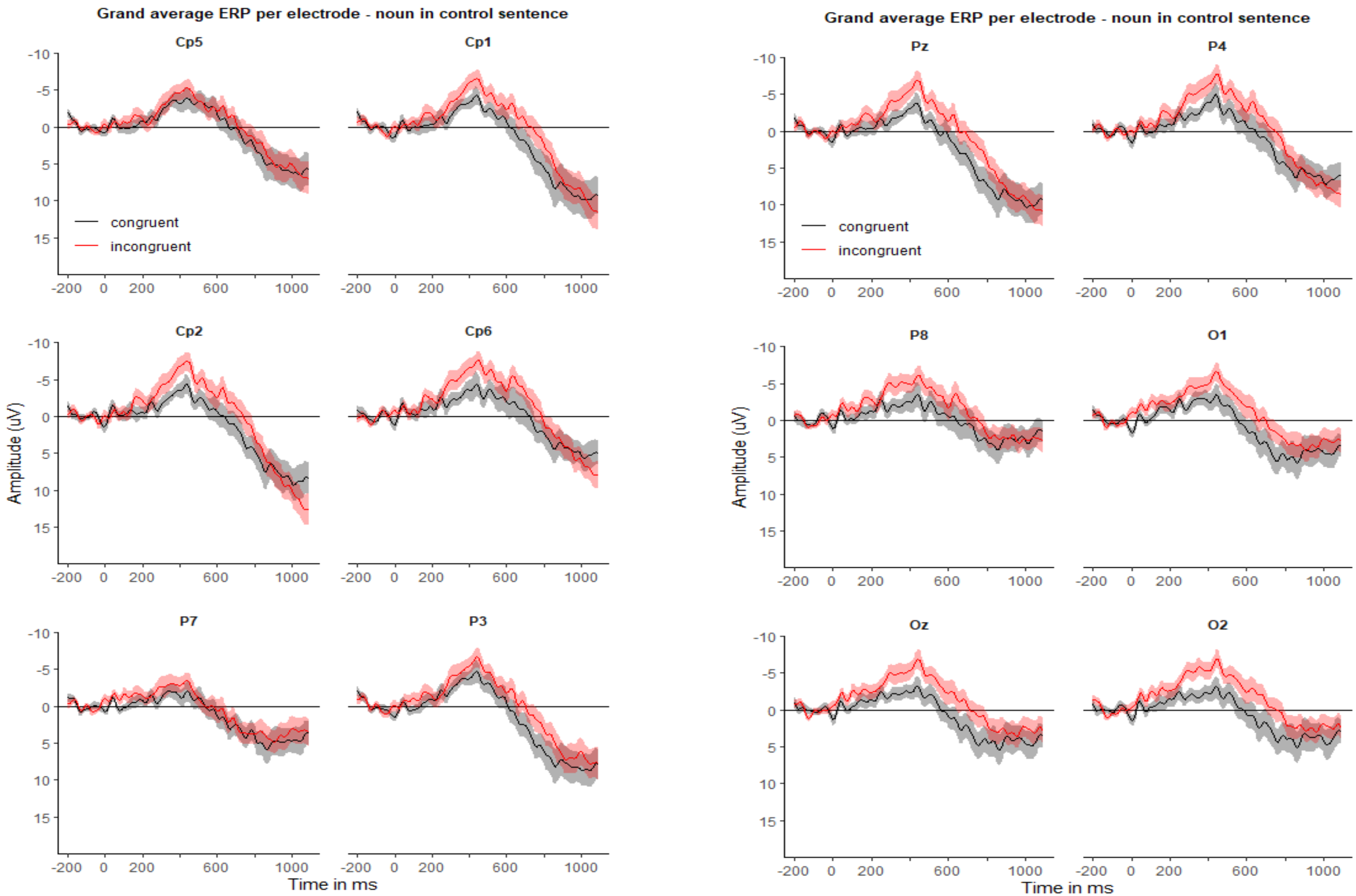
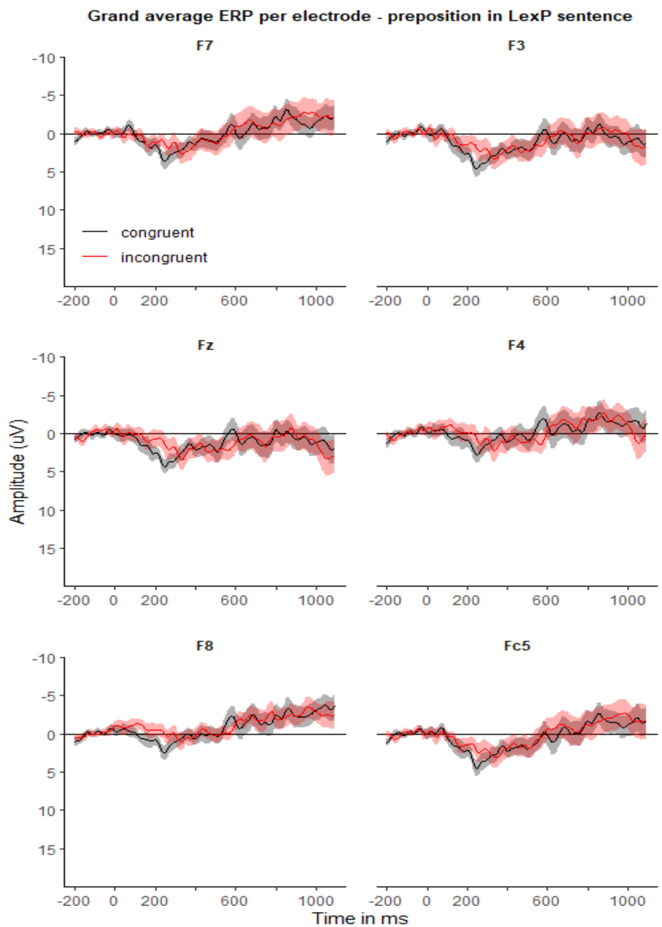
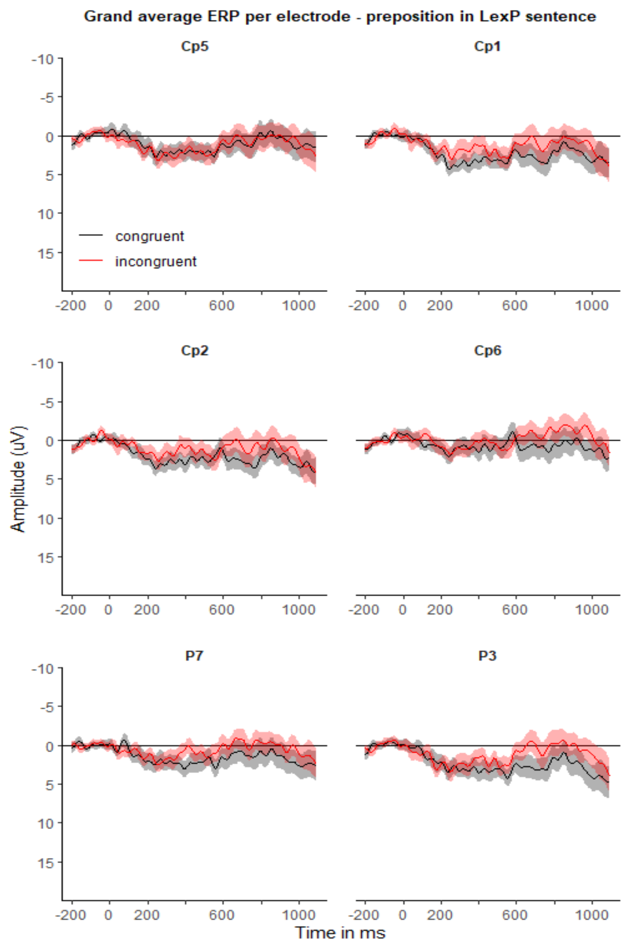


Figure C-2. ERP activity at twenty-four electrode sites relative to nouns in the control sentences. The black lines model activity of the congruent trials and the red lines model incongruent trials. Shaded areas represent confidence intervals. Intervals where the difference between congruent and incongruent trials reaches significance are shown with red dotted lines.



Grand average ERP per electrode - preposition in LexP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Amplitude (uV)
Time in ms



Grand average ERP per electrode - preposition in LexP sentence
Cp5
Cp1
Cp2
Cp6
P7
P3
congruent
incongruent
Amplitude (uV)
Time in ms

A

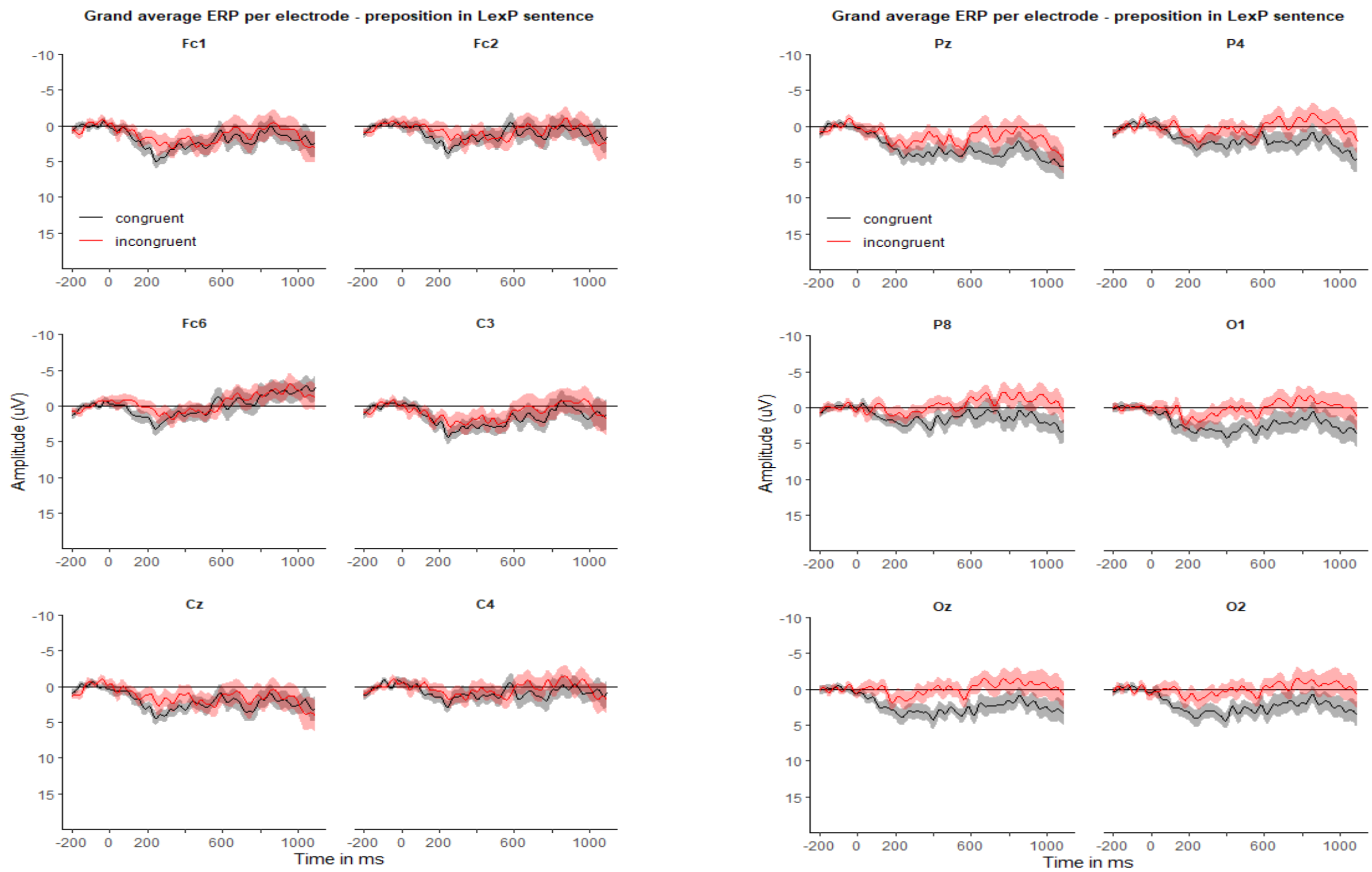
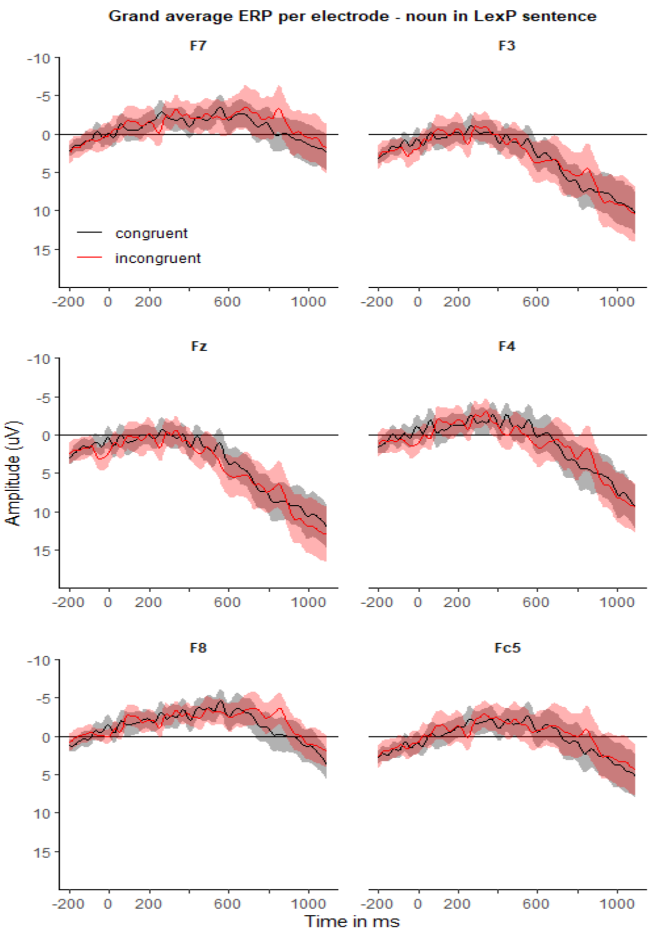
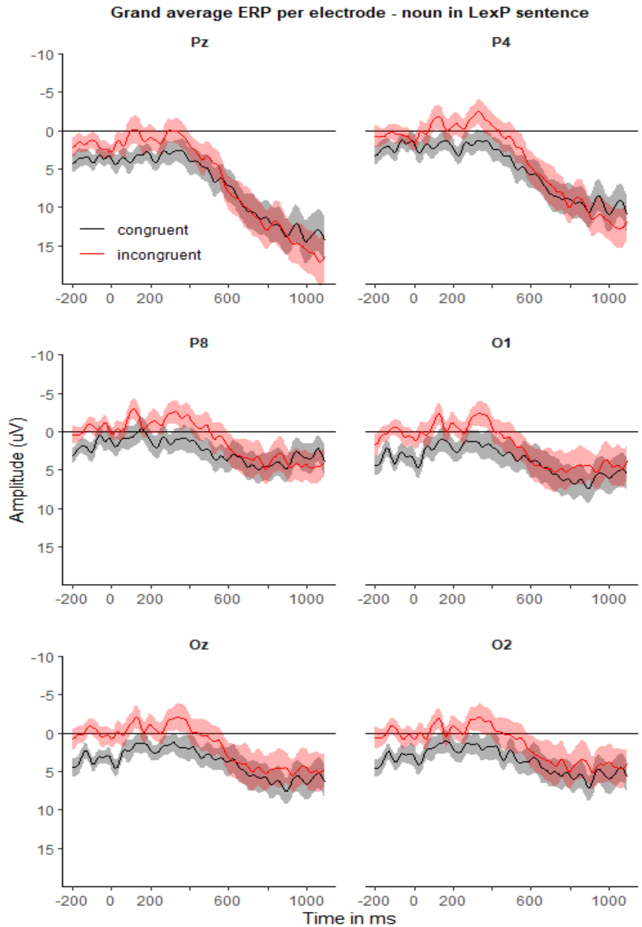


Figure C-3. *ERP activity at twenty-four electrode sites relative to prepositions in LexP sentences. The black lines model activity of the congruent trials and the red lines model incongruent trials. Shaded areas represent confidence intervals. Intervals where the difference between congruent and incongruent trials reaches significance are shown with red dotted lines.*


Grand average ERP per electrode - noun in LexP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Amplitude (uV)
Time in ms


Grand average ERP per electrode - noun in LexP sentence
Pz
P4
P8
O1
Oz
O2
congruent
incongruent
Amplitude (uV)
Time in ms

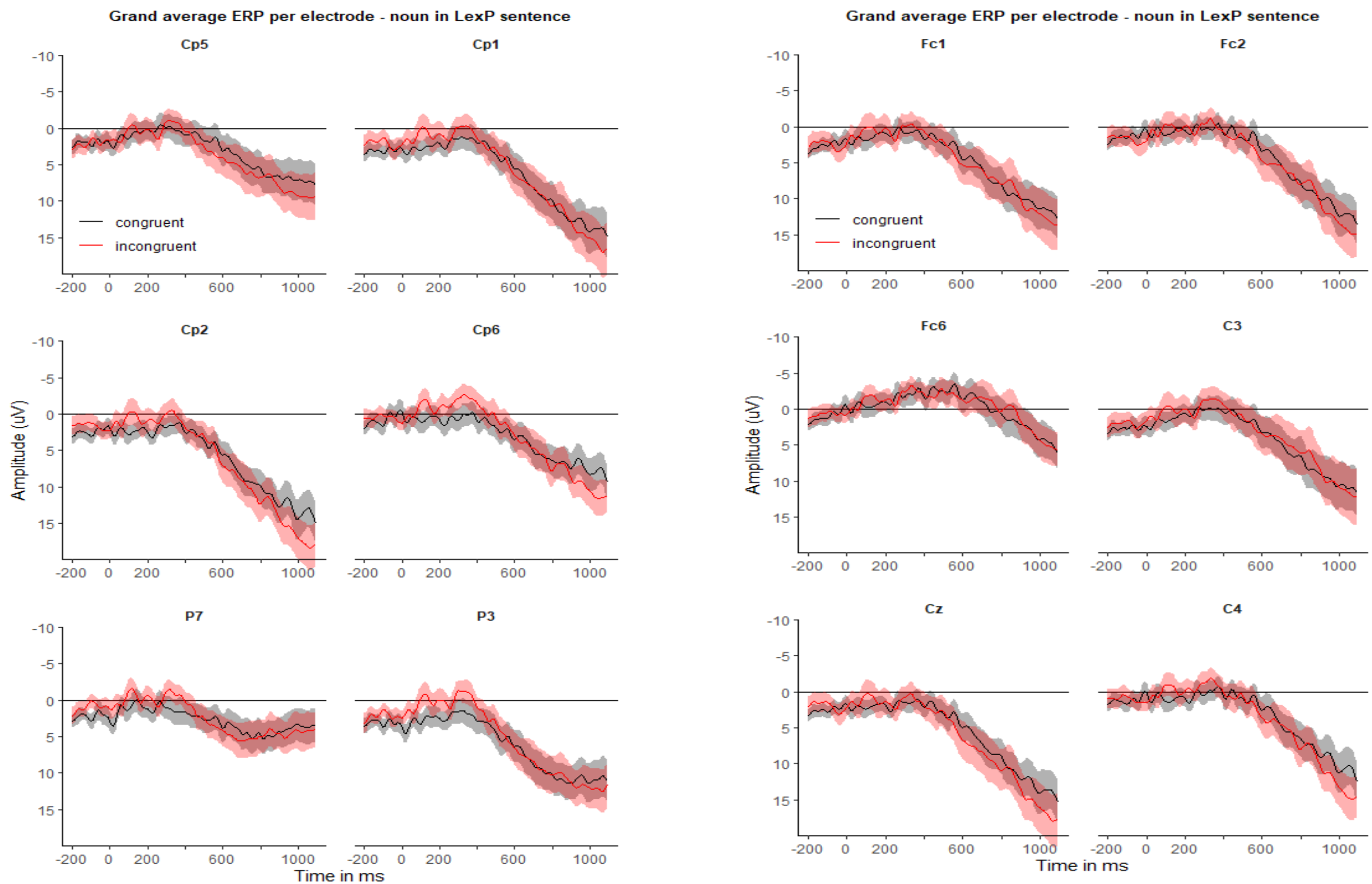
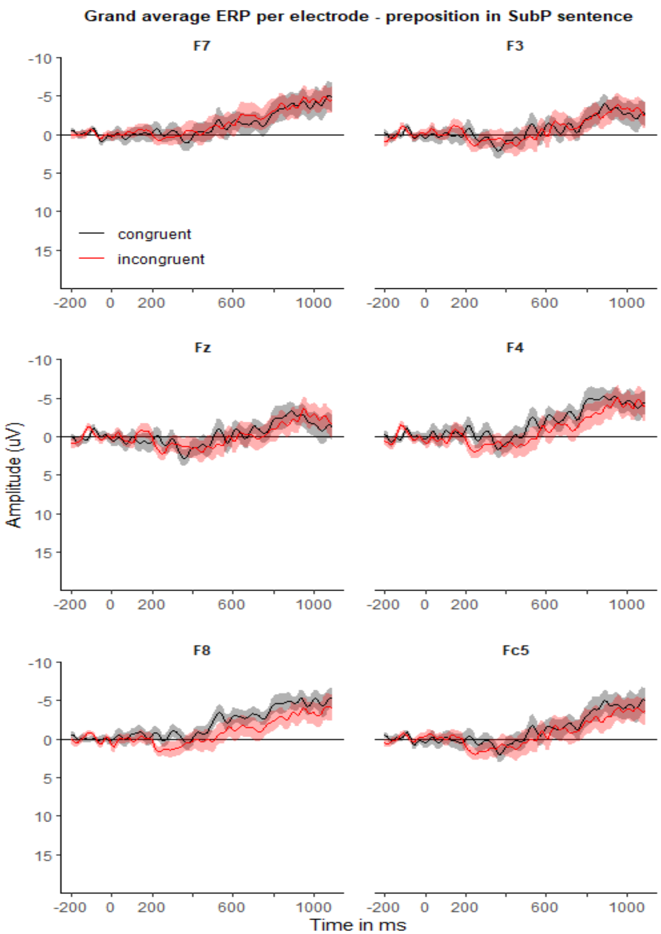
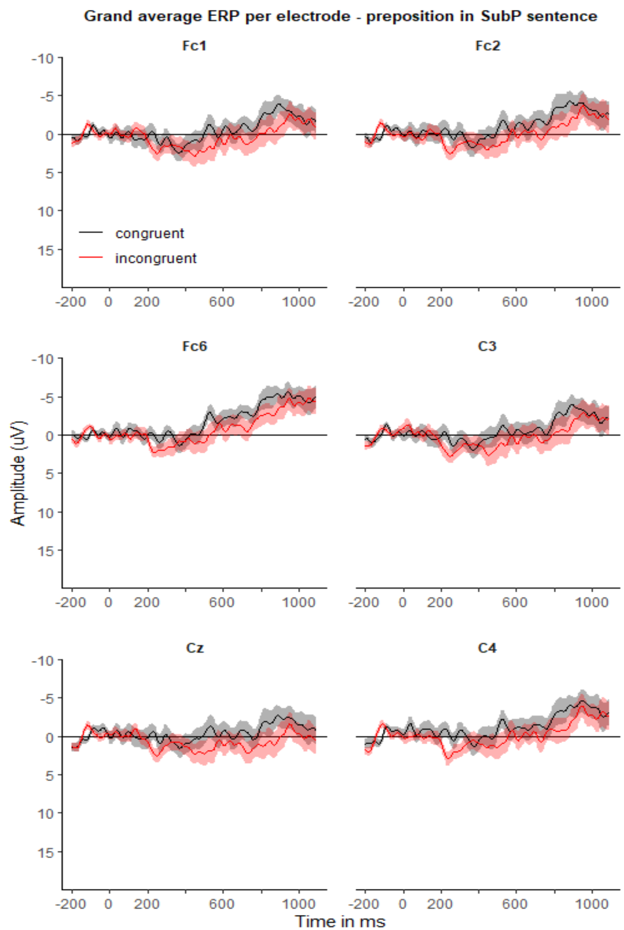


Figure C-4. *ERP activity at twenty-four electrode sites relative to nouns in LexP sentences. The black lines model activity of the congruent trials and the red lines model incongruent trials. Shaded areas represent confidence intervals. Intervals where the difference between congruent and incongruent trials reaches significance are shown with red dotted lines.*


Grand average ERP per electrode - preposition in SubP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Amplitude (uV)
-10
-5
0
5
10
15
-200
0
200
600
1000
Time in ms


Grand average ERP per electrode - preposition in SubP sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Amplitude (uV)
-10
-5
0
5
10
15
-200
0
200
600
1000
Time in ms

A

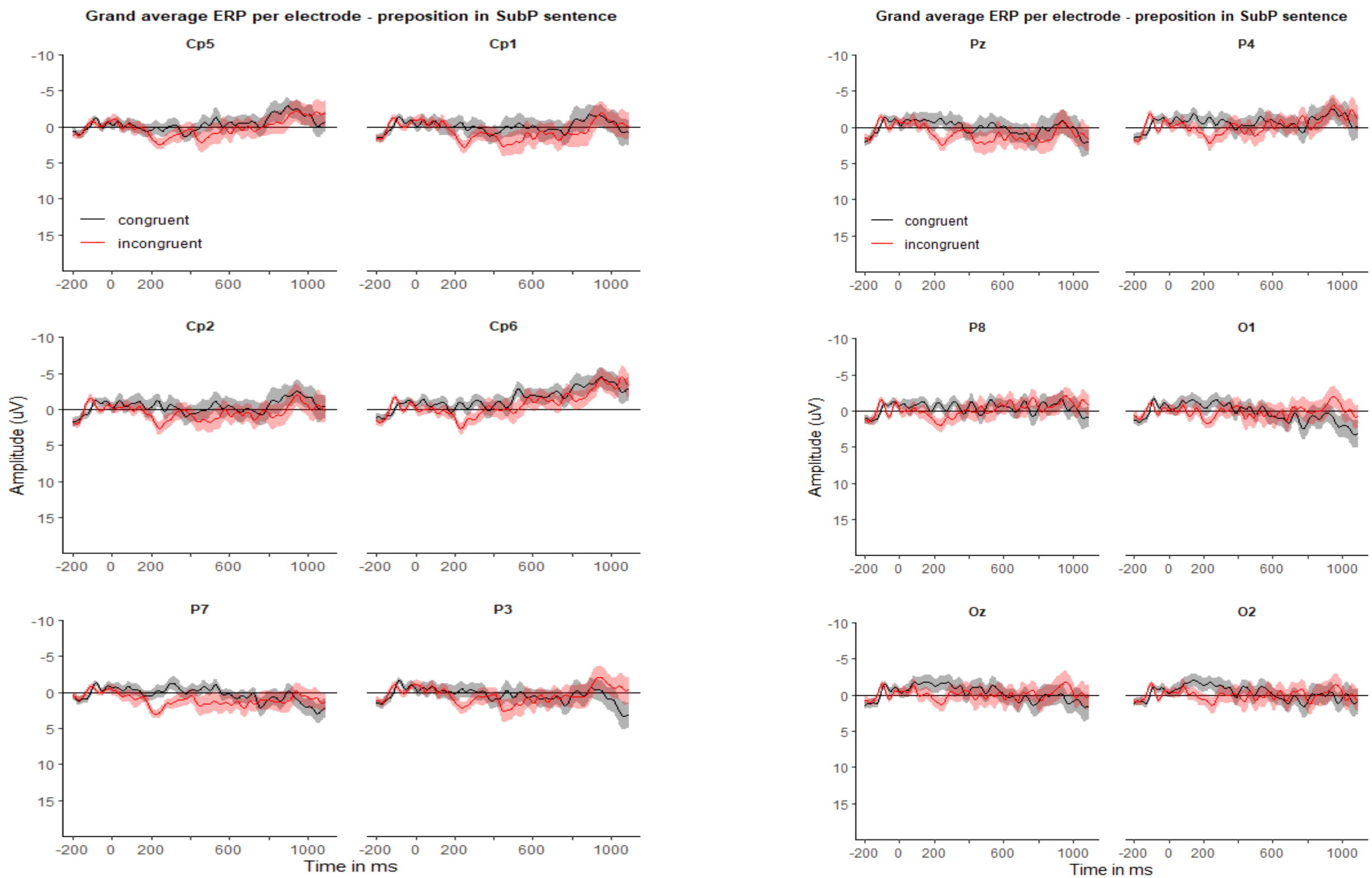
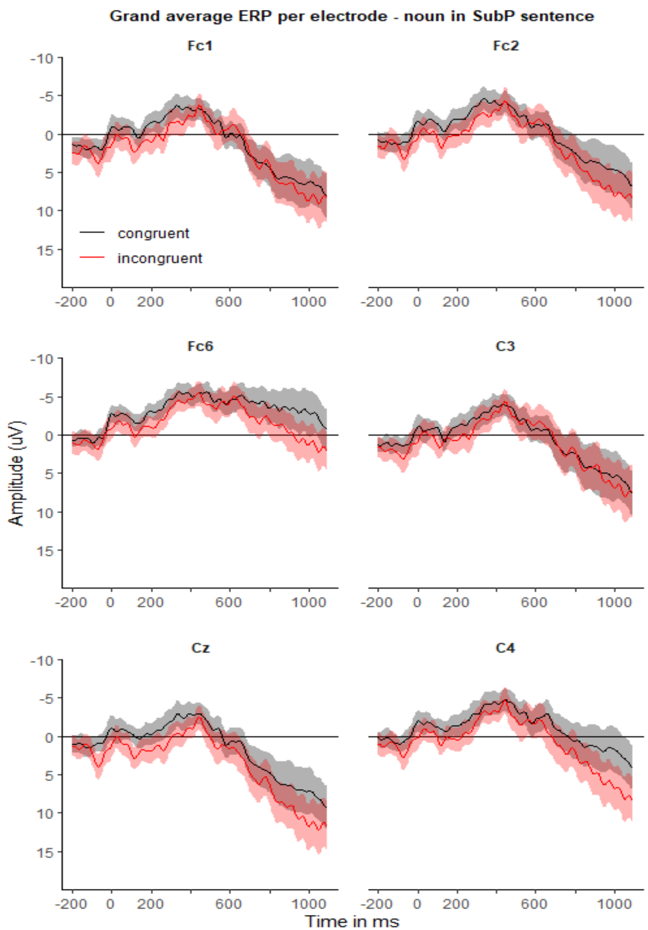
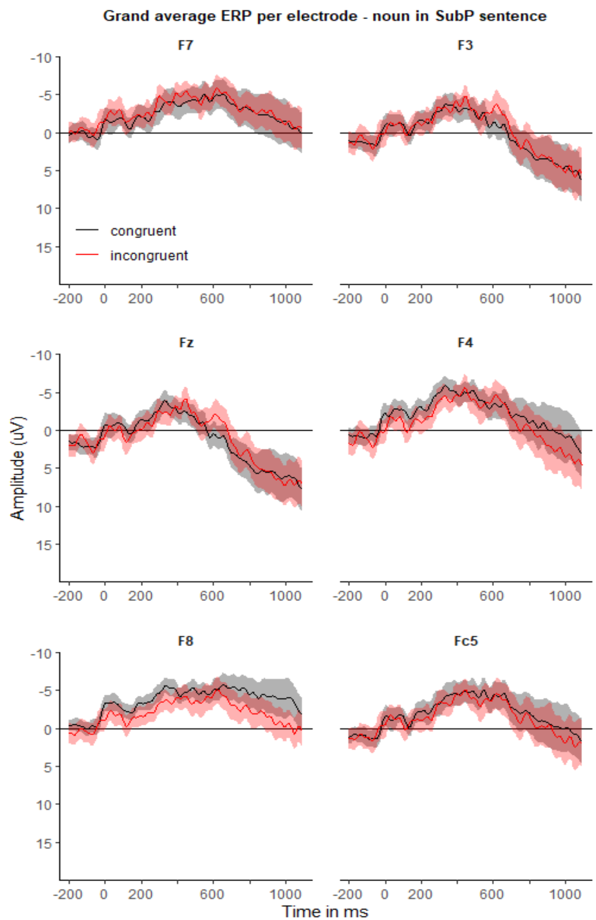


Figure C-5. *ERP activity at twenty-four electrode sites relative to prepositions in SubP sentences. The black lines model activity of the congruent trials and the red lines model incongruent trials. Shaded areas represent confidence intervals. Intervals where the difference between congruent and incongruent trials reaches significance are shown with red dotted lines.*


Grand average ERP per electrode - noun in SubP sentence
Fc1
Fc2
Fc6
C3
Cz
C4
congruent
incongruent
Amplitude (uV)
Time in ms
-10
-5
0
5
10
15
-200
0
200
600
1000


Grand average ERP per electrode - noun in SubP sentence
F7
F3
Fz
F4
F8
Fc5
congruent
incongruent
Amplitude (uV)
Time in ms
-10
-5
0
5
10
15
-200
0
200
600
1000

A

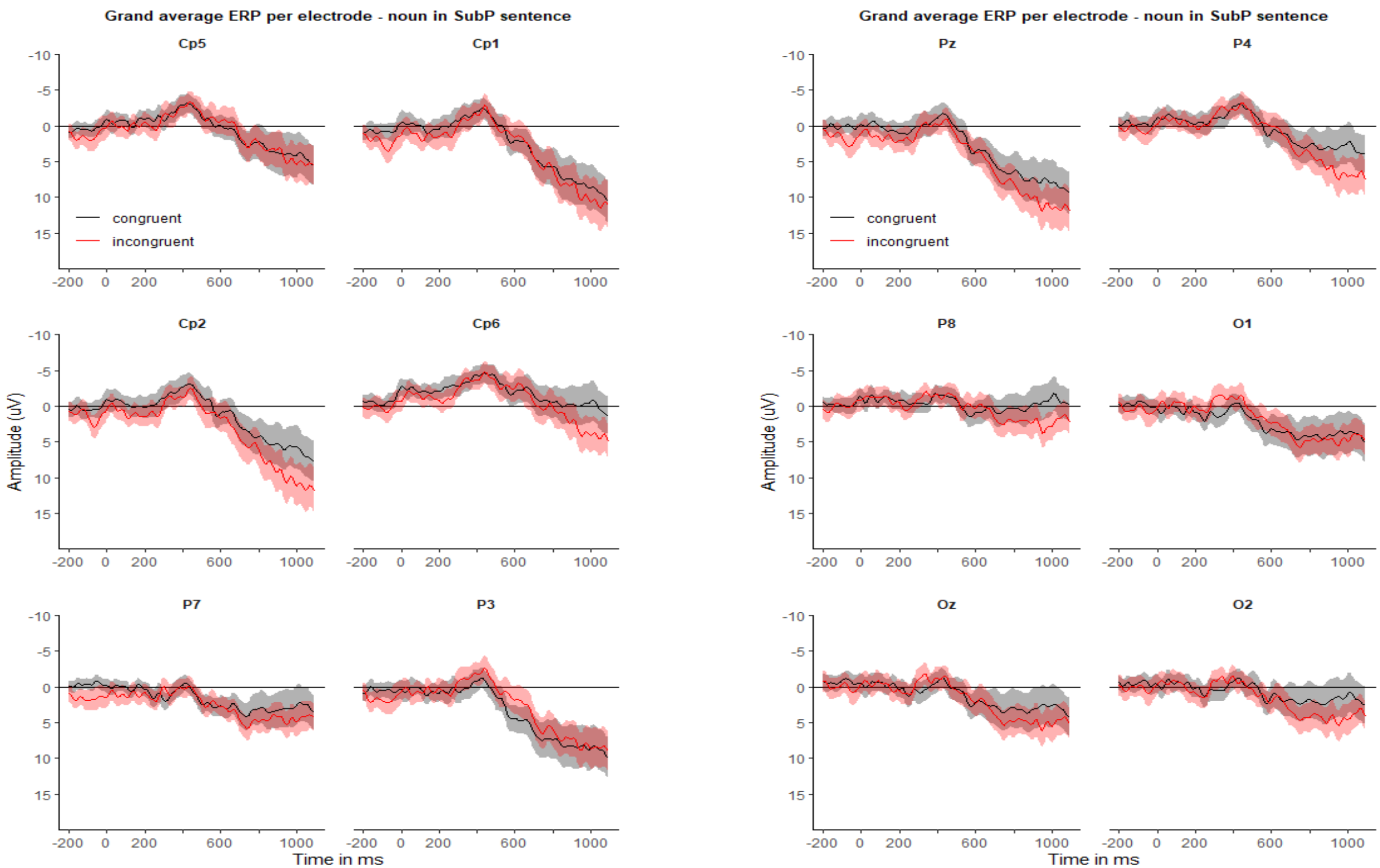
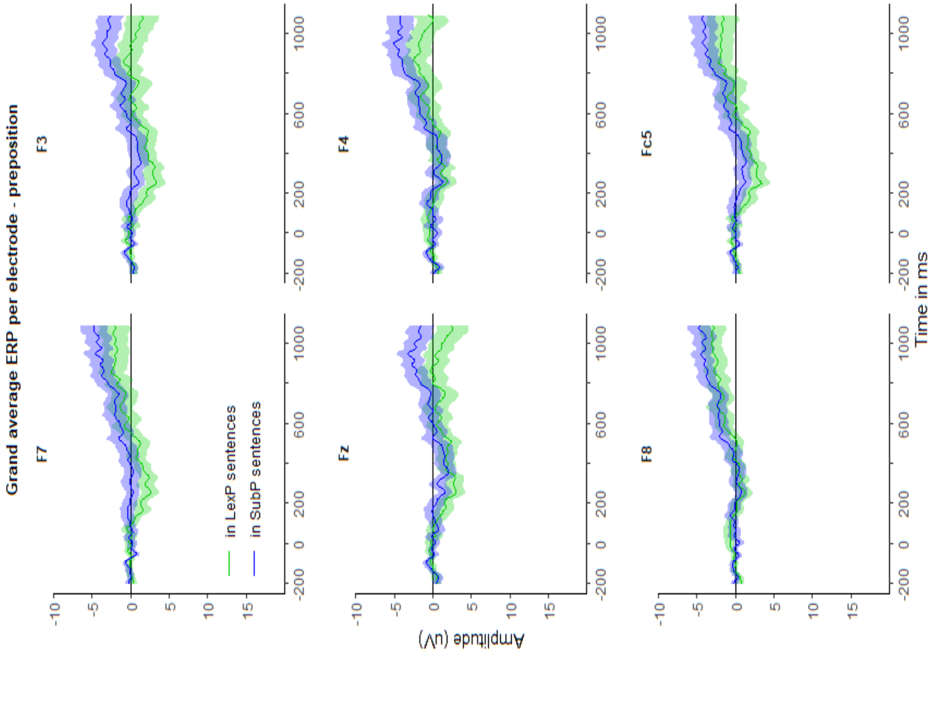
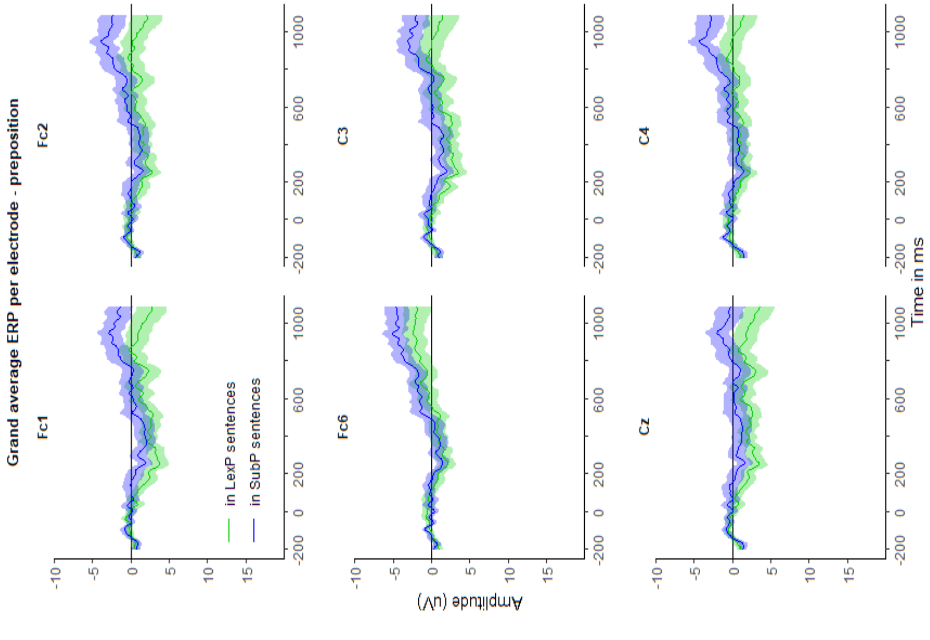


Figure C-6. *ERP activity at twenty-four electrode sites relative to nouns in SubP sentences. The black lines model activity of the congruent trials and the red lines model incongruent trials. Shaded areas represent confidence intervals. Intervals where the difference between congruent and incongruent trials reaches significance are shown with red dotted lines.*



Grand average ERP per electrode - preposition
F7
F3
Fz
F4
F8
Fc5
in LexP sentences
in SubP sentences
Amplitude (uV)
Time in ms



Grand average ERP per electrode - preposition
Fc1
Fc2
Fc6
C3
Cz
C4
in LexP sentences
in SubP sentences
Amplitude (uV)
Time in ms

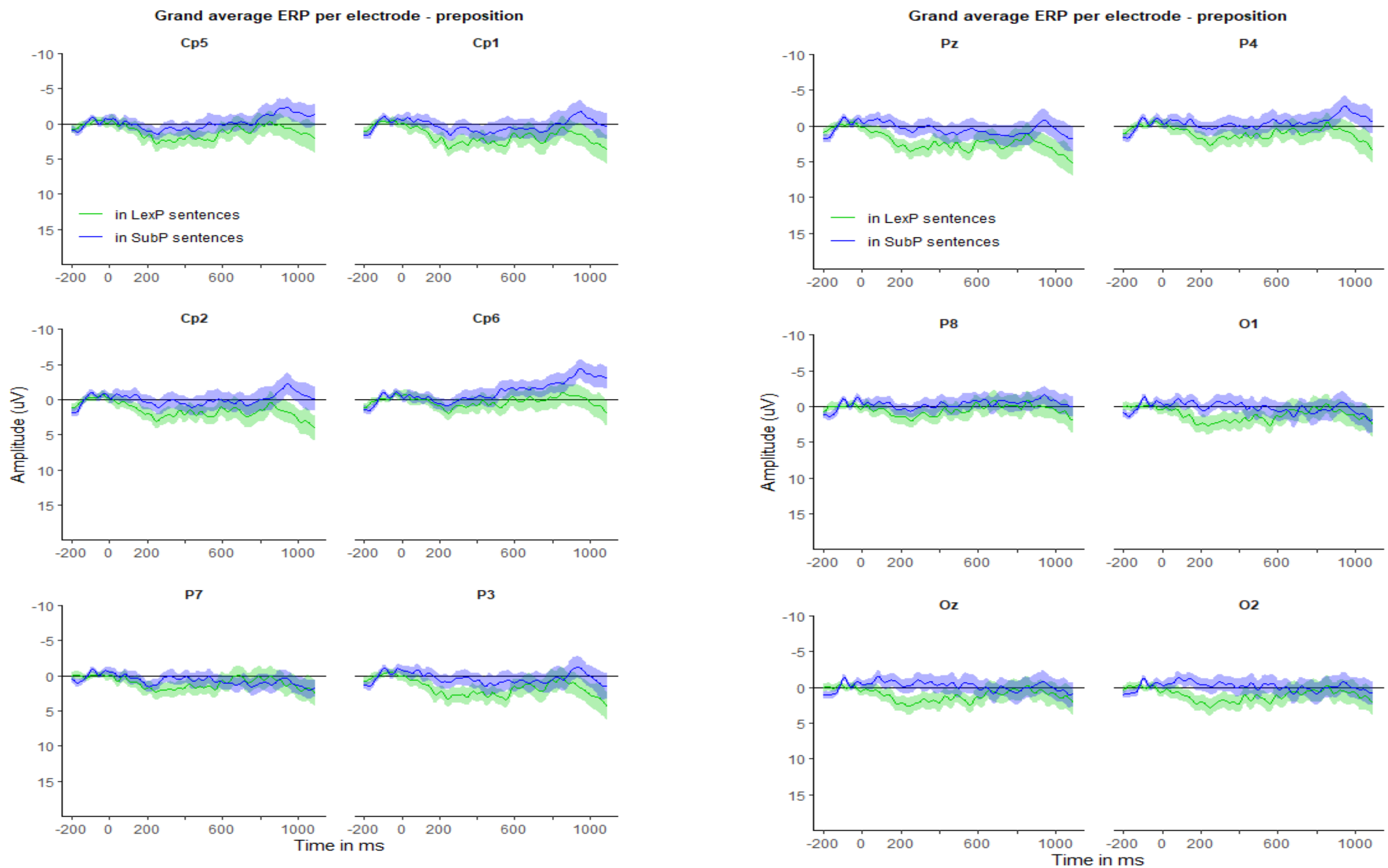
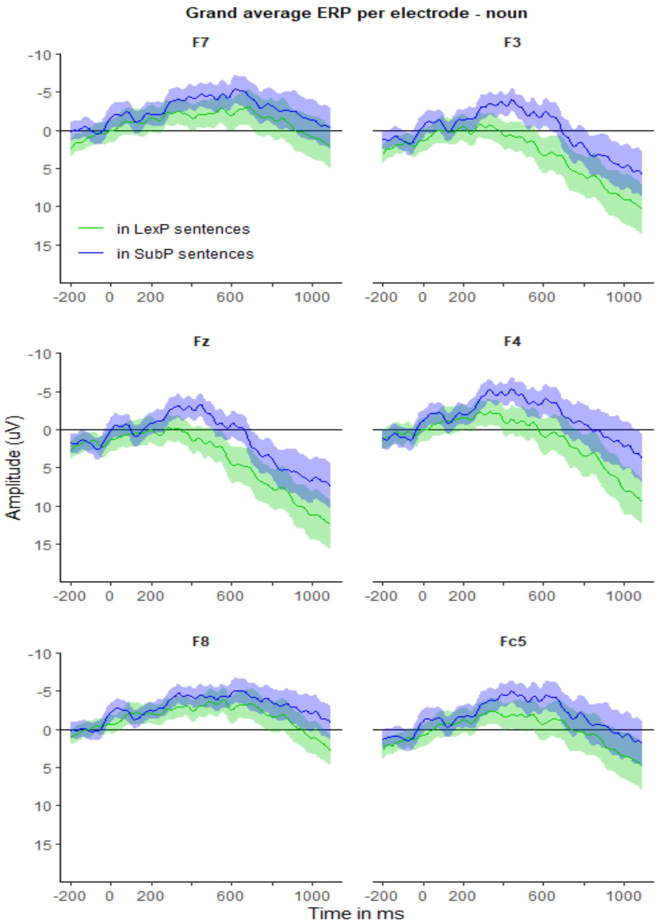
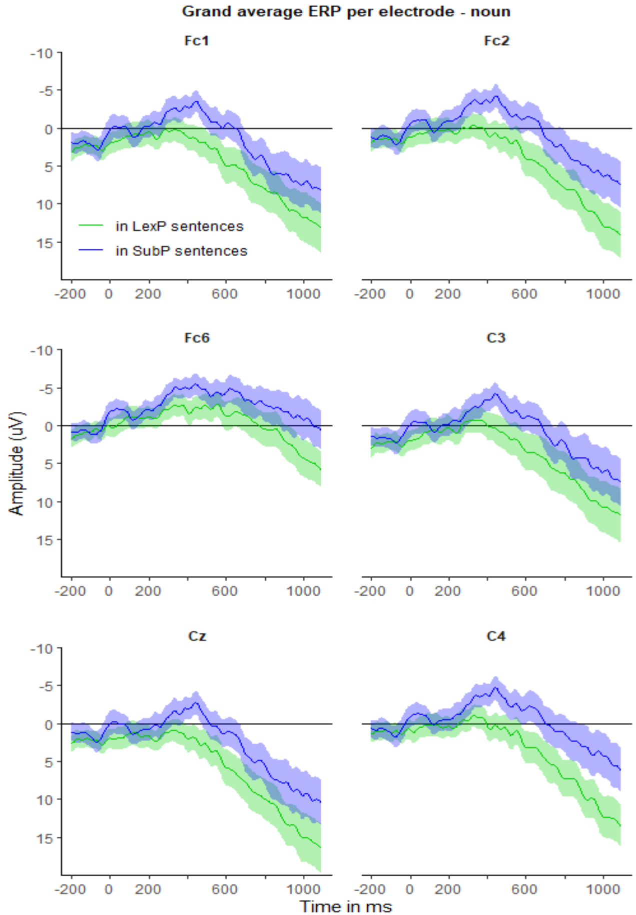


Figure C-7. ERP activity at twenty-four electrode sites relative to prepositions in LexP vs. SubP sentences (congruent and incongruent collapsed). The green line shows activity for LexP sentences, while the blue line shows activity for SubP sentences.


Grand average ERP per electrode - noun
F7
F3
Fz
F4
F8
Fc5
in LexP sentences
in SubP sentences
Amplitude (uV)
Time in ms
-10
-5
0
5
10
15
-200
0
200
600
1000


Grand average ERP per electrode - noun
Fc1
Fc2
Fc6
C3
Cz
C4
in LexP sentences
in SubP sentences
Amplitude (uV)
Time in ms
-10
-5
0
5
10
15
-200
0
200
600
1000

A

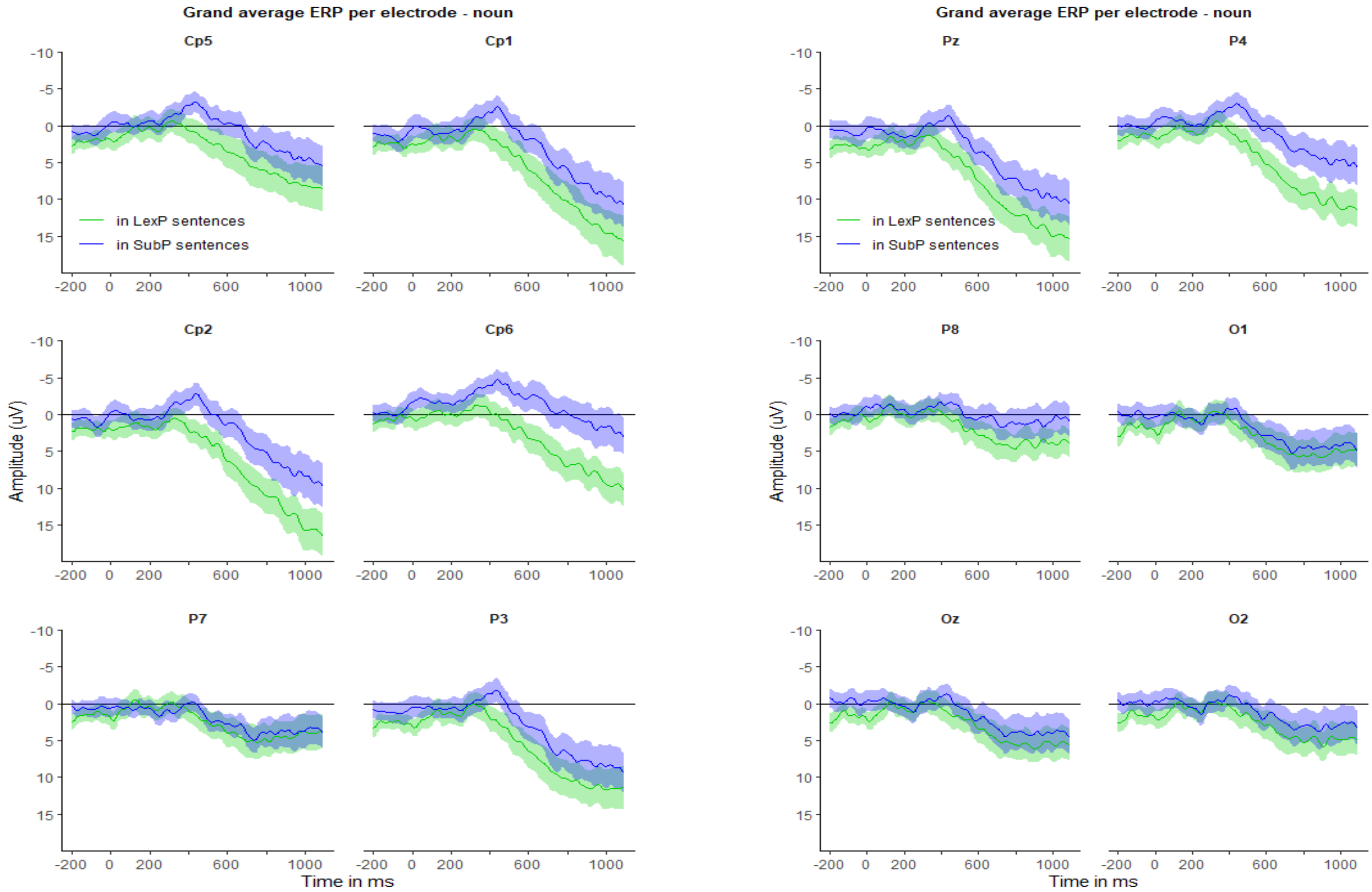


Figure C-8. ERP activity at twenty-four electrode sites relative to prepositions in LexP vs. SubP sentences (congruent and incongruent collapsed). The green line shows activity for LexP sentences, while the blue line shows activity for SubP sentences.

This dissertation investigates the processing of German prepositions through a series of behavioral and ERP experiments with German-speaking adults, typically developing (TD) children and children with cochlear implants (CI).

Syntactic categories (e.g., nouns, verbs, determiners) are typically categorized as either lexical (meaningful) or functional (virtually meaningless). However, theoretical research is not unanimous regarding the syntactic categorization of prepositions. An ERP study with adult participants presents neurophysiological evidence for the categorization of prepositions as a hybrid between lexical and functional categories by demonstrating that prepositions can have properties of both categories depending on usage. The second ERP study presented in this book reveals that children, however, do not show a clear distinction between the processing of prepositions in lexical and functional usage. As such, children's processing of prepositions deviates from the processing of prepositions in adults. A behavioral study with children examines the comprehension and production of prepositions to find out if meaningful prepositions are acquired first, as suggested in the existing literature. This study shows that at least in the age range of 6 to 13 years children do not have a clear preference for meaningful prepositions.
Nevertheless, it is only after the age of 10 years that children's mastery of prepositions becomes similar to that of adults. The final study in this dissertation concerns the comprehension and production of prepositions in children with CIs. The qualitatively degraded sound delivered through CIs can make it challenging for these children to master words which lack perceptual salience (i.e., short or stressless words). Indeed, children with CIs lag behind their TD peers on the comprehension of prepositions, which can present serious obstacles in everyday language use for them. Clinicians are encouraged to design special exercises to enhance the acquisition of prepositions in children with CIs.

Mari Chanturidze