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Research paper

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

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A B S T R A C T

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. We investigated this classification question empirically 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, we conclude that in terms of syntactic categorization, prepositions should be classified as a hybrid between a lexical and functional category.

1. Introduction

1.1. Syntactic categorization of prepositions

There is much controversy among linguists as to whether prepositions constitute a lexical or a functional category (Corver & van Riemsdijk, 2001; Littlefield, 2006). 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 (Baker, 2003; Botwinik-Rotem, 2004; Grimshaw, 1991). This is likely because prepositions are ambiguous with respect to this taxonomy and a uniform classification of prepositions along the functional/lexical axis is difficult to extend to all types of prepositions (Asbury, , Gehrke, , & Nouwen, 2008). For this reason, the status of prepositions as a non-uniform hybrid between lexical and functional categories has also been put forward (Corver & van Riemsdijk, 2001; Littlefield, 2006; Mätzig, 2009; Rauh, 1993;

Zwarts, 1997). The hybrid approach argues that the distinction between 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. In this study we empirically investigate the categorical status of prepositions (i.e., whether prepositions are lexical, functional or a hybrid between the two) in German. Studying lexical and functional usage of prepositions experimentally will be informative not only for theoretical purposes, but also has implications for language acquisition in typical (for more information on prepositions in typical development see Chanturidze, Carroll, & Ruigendijk, 2019) and atypical (e.g., hearing impairment, specific language impairment, intellectual disabilities) development as well as second language acquisition.

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 classed into several types depending on their functional use in language. Broadly speaking, three groups of prepositions are identified (excluding particles and prepositional adverbials[1]), namely, *lexical* (see examples 1 and 2 below for prepositions used for location and time in English and German, respectively), structural, here called *subcategorized* (3) also referred to as grammaticized, collocative, non-lexical or dependent, and so-called *syntactic* (e.g., Bennis et al., 1983; Mätzig, 2009) (see example 4) such as possessive *of*, passive *by* (German *von* both for possessive and passive) or dative *to* (German *zu*)[2] (for a detailed review see Mätzig, 2009). It has been argued that "syntactic prepositions" are case-assigners rather than true prepositions because they have features that are consistent with features of case-assigners (Lindstromberg, 2010; Svenonius, 2004). Their purpose in linguistic structures is to assign case when a noun or an adjective cannot do so (e.g., Chomsky, 1993; Neeleman, 1996, 1997; Ouhalla, 1999). In the current study we address only *lexical* and *subcategorized* prepositions in German. One important reason not to include so-called syntactic prepositions in the current study is methodological. We compare several different prepositions that can be used either lexically or as subcategorized prepositions. This is not possible with syntactic prepositions, since there are only very few (*von* 'by', *zu* 'to'), which are also hard to group, since they are functionally quite different.

1. a. Nina put the book *on/under/at/next to* [$_{DP}$ the table].

b. Nina legte das Buch *an/unter/auf/neben* den Tisch.

Nina put the$_{ACC}$[3] book at/under/on/next to the$_{ACC}$ table

2. a. The meeting takes place *on/after/before* [$_{DP}$Monday].

b. Die Sitzung findet *am/nach /vor* Montag statt.

the$_{NOM}$ meeting takes on/after/ before Monday place

3. a. Everyone picked *on/*in/*under*[4] [$_{DP}$the new student]. (Tseng, 2000)

b. Der Bäcker fragt *nach/*mit/*an* einem Apfel.

the$_{NOM}$ baker asks after/with/ on an$_{DAT}$ apple.

"The baker is asking *for/*with/*on* an apple."

4. a. The younger children are assisted *by* their teachers.

b. Die jüngeren Kinder werden *von* ihren Lehrern unterstützt.

the$_{NOM}$ younger children are by their$_{DAT}$ teachers assisted

In general, several properties have been used to classify different syntactic categories (e.g., nouns, verbs, determiners, etc.) into lexical or functional elements. The most commonly addressed distinctive feature 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 & van Riemsdijk, 2001).

Besides the presence or absence of semantic meaning, several other characteristics for each category have been discussed. For instance, lexical words can determine linguistic properties of their argument both on a semantic (thematic role assignment) *and* on a syntactic level (type of argument) (Rauh, 1993). In contrast, functional elements determine *only* morpho-syntactic features of the arguments (e.g., auxiliary *is* can require to be accompanied by the present participle ending in -*ing*) (Rauh, 1993).

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 of them are 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

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[1] Particles and prepositional adverbials are not considered to be prototypical prepositions. The typical structure for prepositional phrase is PP →P – DP, while particles are prepositional adverbials that do not take arguments (e.g., Bolinger, 1971; van Riemsdijk, 1978). However, several authors suggest particles and prepositional adverbials are prepositions but intransitive (e.g., Jackendoff, 1973).

[2] In English the preposition *for* can also be used syntactically in structures such as "What I want is *for* him to meet the deadline" (Lindstromberg, 2010).

[3] NOM = Nominative case, DAT = Dative case, ACC = Accusative case.

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

examples 1–3 above; cf. Zwarts, 1997; Littlefield, 2006; Rauh, 1993). In the present study we aimed to examine prepositions which are loaded with meaning (lexical prepositions) and prepositions which have hardly any meaning (subcategorized prepositions) in order to see whether the former would be processed similar to other lexical categories and whether the latter will be processed similar to other functional processes.

Let us now consider properties of the lexical/functional divide as applied to prepositions. Prepositions, even the ones that have the same phonetic and orthographic form, carry different linguistic properties. In the English example (1a) and German (1b), *on* and *an,* respectively, express location, i.e., these prepositions are semantically loaded. Not only do these prepositions carry semantic meaning, but they also are polysemous: English *on* in (2a) and German *an/am*[5] in (2b) convey temporal meaning. This feature, namely having relatively specific/detailed semantics prompted theoreticians to suggest that prepositions such as *on* in (1 & 2) belong to a lexical category (similar to noun, verbs, etc.; see Littlefield, 2006; Zwarts, 1997; Rauh, 1993). *On* in English (3a) and *nach* (after) in German (3b), however, are semantically virtually empty – they have no specific referential meaning; the preposition is directly subcategorized (through idiomatic selection) by the verb *pick* and *fragt* (asks) 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 (3) have been suggested to belong to a functional category (such as determiners, complementizers) (Corver and van Riemsdijk, 2001).

Furthermore, *on* in (1a) and *an* in (1b) 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. In contrast, the subcategorized prepositions in (3a) and (3b) cannot easily be replaced by any other preposition without resulting in an unacceptable sentence. This shows that the verb in the given structure requires this specific preposition.

Similarly to lexical categories, lexical prepositions assign thematic roles to their arguments (e.g., location, goal, source, path, and instrumental) and determine the syntactic type of their argument (Littlefield, 2006; Mätzig, 2009). As for subcategorized prepositions, some authors suggest that they do not determine the thematic role of their arguments (Littlefield, 2006; Tseng, 2002), while others (Neeleman, 1997) suggest that subcategorized prepositions are idiomatically selected by the verb in order to assign a thematic role to their complements.

Finally, note that processing differences between the different preposition usages (lexical, subcategorized) have been reported for language acquisition. Friederici, 1983 studied reaction times and errors for three types of prepositions in German, namely, lexical, obligatory (here subcategorized) and verb particles. The study found that young children (5 years) performed much better on meaningful lexical prepositions than on prepositions, which lack meaning.

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 and Van Riemsdijk, 2001). A short summary of the characteristic properties of each type of preposition is given in Table 1.

To summarize, we assume that the linguistic properties of lexical prepositions are more characteristic of lexical categories (verbs, adjectives, etc.), while the properties of subcategorized prepositions are more characteristic of functional categories (determiners, inflection, complementizers, etc.), i.e., they play a primarily syntactic role in language.

1.2. Event-related potentials (ERPs) related to lexical-semantic and structural processing

Linguistic theory regarding the general dichotomy between lexical and functional words has been supported by language processing studies. For instance, functional words are accessed faster than lexical words (Segalowitz & Lane, 2000). In fMRI studies, differences in the degree of activation in specific brain regions as well as preferential activation of brain regions depending on the word class (i.e., lexical or functional) have been observed (e.g., Diaz & McCarthy, 2009). Furthermore, ERP studies have suggested different electrophysiological markers (difference in peak latencies) for lexical and functional words (Brown, Hagoort, & Ter Keurs, 1999; Neville, Mills, & Lawson, 1992). Moreover, ERP effects for functional words are typically left lateralized, whereas the effects for lexical words are equally distributed over both hemispheres (Neville et al., 1992; Pulvermüller, Lutzenberger, & Birbaumer, 1995).

ERP studies have provided evidence for a separation between lexical-semantic and syntactic/structural 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, 2011; Friederici, Hahne, & Saddy, 2002; Kutas & Hillyard, 1980).

For instance, in (5) 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*.

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

Clearly, *sky* in (5) 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

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[5] *am* represents an amalgamation of the preposition *an* and the definite determiner in the dative case, *dem*.

Table 1

Characteristic properties of lexical and subcategorized prepositions.

Features/Properties	Lexical	Subcategorized
Relatively specific semantic meaning	Yes	No (non-conceptual meaning)
Structural independence	Free-standing	Dependent
Class membership	Closed	Closed
Thematic role assignment	Yes	Not clear/controversial
Case assignment	Yes	Yes

differences in semantic expectancy as between *mouth* and *pocket* in (6), where both words are possible, but *mouth* is the preferred continuation, and *pocket* merely less expected can modulate the N400 amplitude.

6. 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 and Federmeier, 2011). Furthermore, studies in 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, Stewart, & Phillips, 1990; Hagoort & Brown, 2000; Van Den Brink, Brown, & Hagoort, 2001). The first negative shift is referred to as N200 or as 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. Similarly 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 a P600 (or late positive) component - a positive deflection peaking roughly between 500 and 900 ms after stimulus onset (e.g., Friederici, 2011; Kaan, 2007; Kaan & Swaab, 2003; Osterhout et al., 1994). This late positive component has been observed in response to processing of syntax-related violations (7) or structural ambiguities (8), which necessitate cognitive mechanisms associated with syntactic manipulations such as reanalysis, repair, or integration in complex structures (for a review see Bornkessel-Schlesewsky & Schlesewsky, 2009).

7. The man in the restaurant doesn't like the hamburger that is/*are on his plate. (Kaan & Swaab, 2003).

8. 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, 1993; Molinaro, Barber, & Carreiras, 2011) as in (7) and (9). Hagoort et al. (1993) observed a P600 for the processing of number agreement mismatch between the subject and verb of sentences in Dutch (9).

9. *Het verwende kind gooien het speelgoed op de grond. (Hagoort et al., 1993)

"The *spoilt* child$_{SG}$ throw$_{PL}$ 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 to syntactic features that mark the grammatical relation between arguments and verb (Friederici, 2011, but see Steinhauer & Drury, 2012 for discussion). For example, a biphasic ERP pattern LAN and P600 as a result of processing agreement violations has been reported by a number of studies (for review see Molinaro et al., 2011). Molinaro, Vespignani, and Job (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 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, Kreher, Sitnikova, Caplan, & Holcomb, 2007; Van Herten, Kolk, & Chwilla, 2005; for a detailed discussion regarding the interpretation of "semantic" positivities see; Bornkessel-Schlesewsky & Schlesewsky, 2009; Kuperberg et al., 2007; Brouwer, Fitz, & Hoeks, 2012).

Roehm, Bornkessel-Schlesewsky, Rösler, and Schlesewsky (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, Stowe, and Doedens (2004) also reported a biphasic N400/P600 effect in relation to syntactically correct Dutch sentences such as in (10).

Table 2

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

10. De speer heeft de atleten opgesomd

the javelin has the athletes summarized

"The javelin summarized the athletes."

In (10) 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 the processing problems originating from semantic or thematic processing difficulties.

In sum, substantial evidence has accumulated in language-related electrophysiological research concerning the processing of semantic and (morpho)syntactic difficulties. In light of this theoretical and empirical evidence, we addressed the categorical status of prepositions with an ERP study. We 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. This should result in different ERP components. More specifically, we expected an N400, a component related to lexical-semantic processing difficulties, in sentences with a violation of the lexical preposition (for examples, see Table 2). In sentences with subcategorized prepositions, a P600 component related to structural/syntactic reanalysis was expected (Table 2). Although anterior negativities have been observed for the processing of syntactic violations, we did not expect to find this component as a result of our experiments due to the specific design of our 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 (see below). Thus, since it has been argued in the literature (Friederici, 2001; Swaab, Ledoux, Camblin, & Boudewyn, 2012) that a P600 is correlated with both outright violations _and_ dispreferred structures, and an (E)LAN has been elicited for actual violations, we expected to find a P600 and not an E(LAN) in sentences with manipulated subcategorized prepositions.

2. Materials and methods

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.

2.2. Experimental material

2.2.1. Sentence design

The experimental stimuli were auditorily presented sentences in German, each containing one out of twelve mono-syllabic 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 (in Appendix B we show how often each preposition is used per condition in Table 13S). 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).[6] After selecting the 12 most frequent prepositions from the CHILDES database, we tried to create the experimental stimuli so that for sentences with lexical prepositions the preposition had clear semantic content as for example, "The man is carrying a package _in_ a bag", where _in_ has a clear content referencing to a location, whereas for sentences with subcategorized prepositions the preposition had virtually no meaning as for example, "Everyone picked _on_ a new student" where _on_ has no content and is arbitrarily selected by the verb. We avoided creating

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[6] The CHILDES database was used because the same linguistic materials are employed in a follow-up study with children.

sentences such as "The researchers rely *on* the secondary sources" in which although the verb and the preposition represent a unit that carries specific content, *on* still makes a certain semantic contribution.

Congruent and incongruent sentences were constructed as minimal pairs where only the critical preposition was manipulated (see Table 2). There were 41 minimal pair sentences for lexical and 41 minimal pair sentences for subcategorized prepositions (see Appendix B). We refer to sentences with lexical prepositions as LexP sentences and to sentences with subcategorized prepositions as SubP sentences. Most prepositions were used in both conditions of LexP and SubP sentences (see Table 13S in Appendix B). In congruent LexP only *für* was not used and in incongruent LexP – only *um*. 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, in* were not used in this condition. However, we included all 12 prepositions in the incongruent condition of SubP sentences. All sentences contained transitive verbs. In LexP sentences, the prepositional phrase (PP) was an adjunct after the argument DP. All verbs were mono-syllabic in their conjugated forms (bi-syllabic in the infinitival forms). According to the Leipzig Corpora Collection (Biemann, Heyer, Quasthoff, & Richter, 2007) the verbs in LexP sentences ranged from 7 to 17 frequency classes[7] (median 10; mean 10.8 SD 3.1) and the verbs in SubP sentences ranged from 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 frequency classes.

The experiment also included 82 filler sentences of similar length and lexical material to the experimental sentences, but without prepositions. This resulted in a total of 246 sentences. Average duration and duration ranges of LexP, SubP and filler sentences in each condition (congruent and incongruent) are given in Table 3.

In each experimental sentence, we triggered two critical words for the later electroencephalogram (EEG) analysis, namely, at the beginning of the preposition, which was manipulated to create congruent and incongruent minimal pair sentences, and at the beginning of the final noun (which is also the last word; see underlined words in Table 2). This has 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 verb and a lexical preposition are possible as pretested with German native speakers (see next section). We therefore argued that the processing difficulty would be more readily detectable on the noun in the context of an incongruent preposition 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, we manipulated prepositions both in LexP and SubP sentences 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.

2.2.2. Pretesting

We carried out two pretests before the experiment on separate groups of participants. First, sentence acceptability was examined for all sentence types in all conditions (including the fillers). 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). We rejected sentence pairs where 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 congruent and incongruent LexP sentences included in the experiment was 2.0 (SD 0.7) and 5.1 (SD 0.7), respectively and for congruent and incongruent SubP sentences 1.9 (SD 0.7) and 5.0 (SD 0.7), respectively.

After this, to assess whether all prepositions allow for a sensible sentence completion in the experimental sentences (no fillers were tested here), we employed a sentence completion task. 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. We did not include congruent SubP sentences 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. We asked participants on the pretest 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 we wanted to examine in how far prepositions allowed for appropriate sentence completions.

Furthermore, to control the level of difficulty for integrating prepositions into the context for congruent and incongruent LexP

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[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 21–24.

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

Table 3

Average duration and duration ranges in milliseconds for LexP, SubP and filler 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
Fillers congruent	2765 (SD 184)	2378–3192
Fillers incongruent	2690 (SD 220)	2354–3400

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 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.

2.3. Presentation and procedure

2.3.1. EEG recording

The EEG signal 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 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, Büchner, Ruigendijk, Meyer, & Sandmann, 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, Luu, Russel, & Tucker, 2001). In fact, keeping a higher impedance threshold has a number of advantages such as less preparation time and avoidance of hygienic issues.

2.3.2. Experimental design and procedure

After the EEG cap mounting procedure, 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 min each. After 4 blocks they were given an opportunity for a break of a maximally 10 min, 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 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 a sentence presentation 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, which remained on the screen until the 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.

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

2.4. Data analysis

2.4.1. EEG analysis

EEG data were analyzed with MATLAB 8.1.0.604 (R2013a; Mathworks, Natick, MA) and EEGLAB (version 13.4.4b, Delorme & 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, Ruigendijk, Scherbaum, & Bleichner, 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. The overall percentage of trials rejected for sentences with lexical prepositions was 21.79% (range: 13.41–30.49%). The overall percentage of trials rejected for sentences with subcategorized prepositions was 21.34% (range: 12.2–31.71%).

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, Hentschel, & Zeller, 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).

2.4.2. Statistical analysis

All analyzable trials were included in the ERP analyses (the number of observations for each analysis is given in the respective LMM tables in the supplementary materials).

We determined the time windows for statistical analyses for the expected N400 and P600 components 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 2):

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/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, Davidson, & Bates, 2008). Analyses were carried out using R (R Core Team, 2014) and the lme4 package for linear mixed-effects models (LMMs; Bates, Mächler, Bolker, & Walker, 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, we also analyzed the difference waveforms, which were computed by subtracting the waveform to a congruent critical word from the waveform to an incongruent critical word. This analysis was conducted in three time windows for comparing 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 550–1000 ms time window was tested. The LMM model for the difference waveform analysis included participants as a random factor, whereas factors sentence type (LexP vs. SubP), laterality (left, central, right), and anteriority (anterior vs. posterior) were modeled as fixed effects.

3. Results

3.1. Behavioral results

Participants' overall accuracy on the sentence acceptability judgement task was 95% (SD 3.08). Accuracy on LexP congruent sentences reached 92.3% (SD 7.1) and on LexP incongruent 97.3% (SD 3.7). Accuracy on SubP congruent sentences was 93.8% (SD 5.8) and on SubP incongruent it was 96.1% (SD 2.8).

3.2. ERP results

Crucial to the hypothesis of the study, the critical words in LexP sentences and SubP sentences elicited qualitatively different ERP
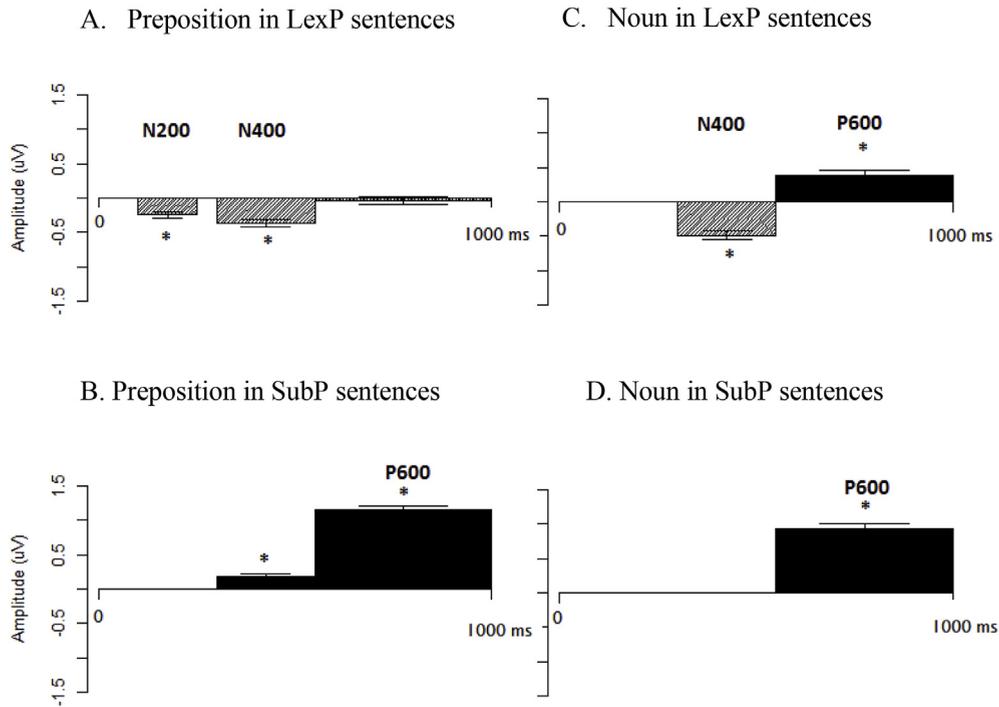
Fig. 1. Polarity and estimated effect sizes in microvolts for each critical word in early and late time windows. Panel A shows the three time windows (100–250 ms; 300–550 ms; 550–1000 ms) analysed following the prepositions in LexP sentences. Panel B shows the time windows (300–550 ms & 550–1000 ms) analysed following prepositions in SubP sentences. The time windows analysed (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) analysed for the nouns in SubP sentences. Solid black bars represent positive effects and shaded bars negative effects.

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 (Fig. 1, Panel B). The results are discussed in more detail in the following sections.

3.2.1. Sentences with lexical prepositions

Grand average ERPs and topoplots for lexical prepositions are given in Fig. 2.

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 4). 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 Supplementary Table 1S 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 the supplementary tables.

In the consecutive time window in which we expected an N400 (300–550 ms) after the preposition, 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 4). 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 (Table 3S in the supplementary materials).

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). Furthermore, in the late time window (550–1000 ms), i.e., for the P600 effect, a significant main effect of condition with the incongruent condition showing a stronger positivity than the congruent condition was found. Also, a significant condition by anteriority interaction was found following the noun (Table 5), indicating that the condition effect was stronger at posterior electrodes. Grand average ERPs and topoplots for the nouns in LexP sentences are given in Fig. 3.
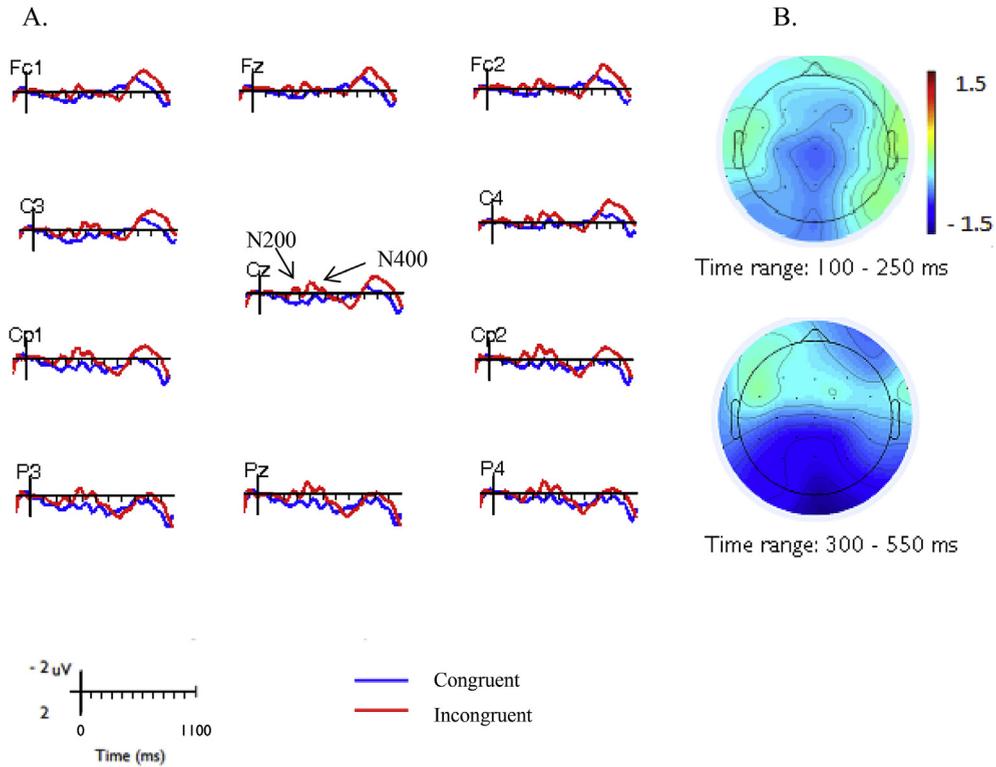
Fig. 2. Panel A shows grand average ERPs for congruent (blue line) and incongruent (red line) lexical prepositions. The onset of the preposition is at 0 ms. Panel B gives topographical information for the N200 (time range 100–250 ms) and N400 (time range: 300–550 ms) effects. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
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 the supplementary materials (Tables 1S–2S).

	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; '**' < 0.01; '*' < 0.05; '.' < 0.1.

Table 5
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 the supplementary materials (Tables 4S–5S).

	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; '**' < 0.01; '*' < 0.05; '.' < 0.1.

3.2.2. Sentences with subcategorized prepositions

Fig. 4 depicts grand average ERPs and topoplots for prepositions in SubP sentences.

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 6). In this time window, the incongruent condition elicited a stronger positivity relative to the congruent condition for the subcategorized preposition. The interaction effects suggest that the P600 effect was strongest at electrodes over centro-parietal areas.

We tested the early time window for the N400 effect (300–550 ms) for subcategorized prepositions as well to compare with the
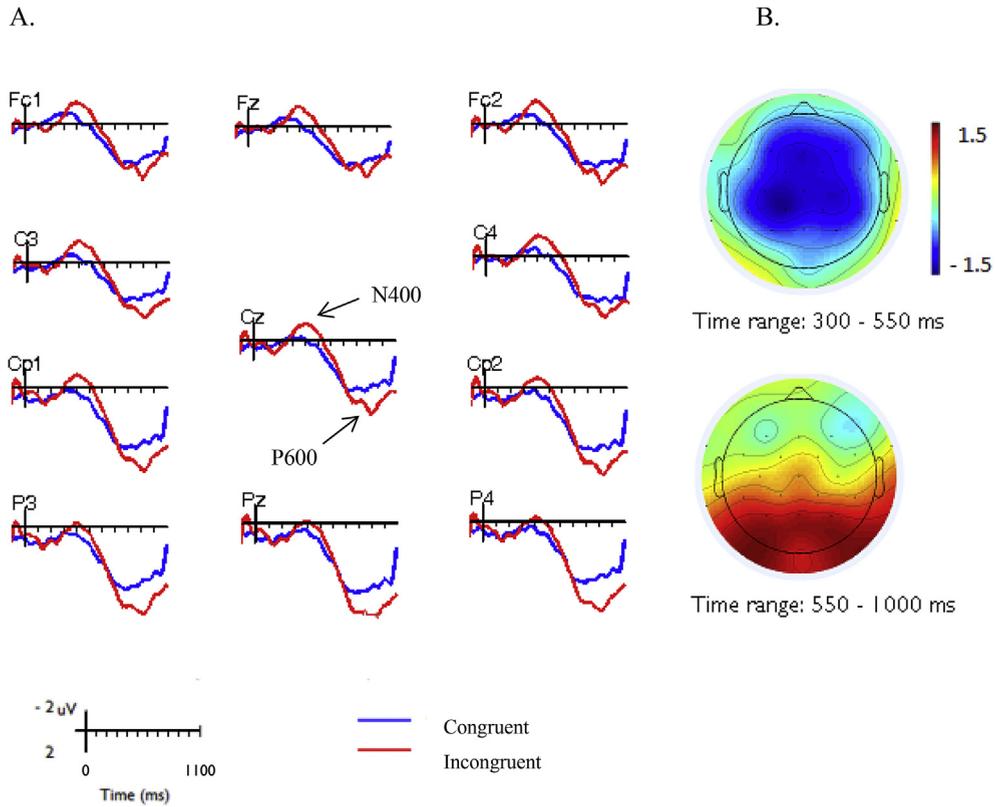
A.

B.

Fig. 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. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 6
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 supplementary materials (Table 7S).

	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: '***' $p < 0.001$; '**' < 0.01; '*' < 0.05; '.' < 0.1.

Table 7
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 the supplementary materials (Table 8S).

	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: '***' $p < 0.001$; '**' < 0.01; '*' < 0.05; '.' < 0.1.

analyses of the lexical prepositions, but no negative-polarity condition effect or any interaction was found (Table 6S). Instead we 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 both the main effect of condition and the condition by anteriority interaction were significant (Table 7), indicating a P600 effect most prominent over posterior regions (see Fig. 5 for the grand average ERPs for the nouns in SubP sentences).
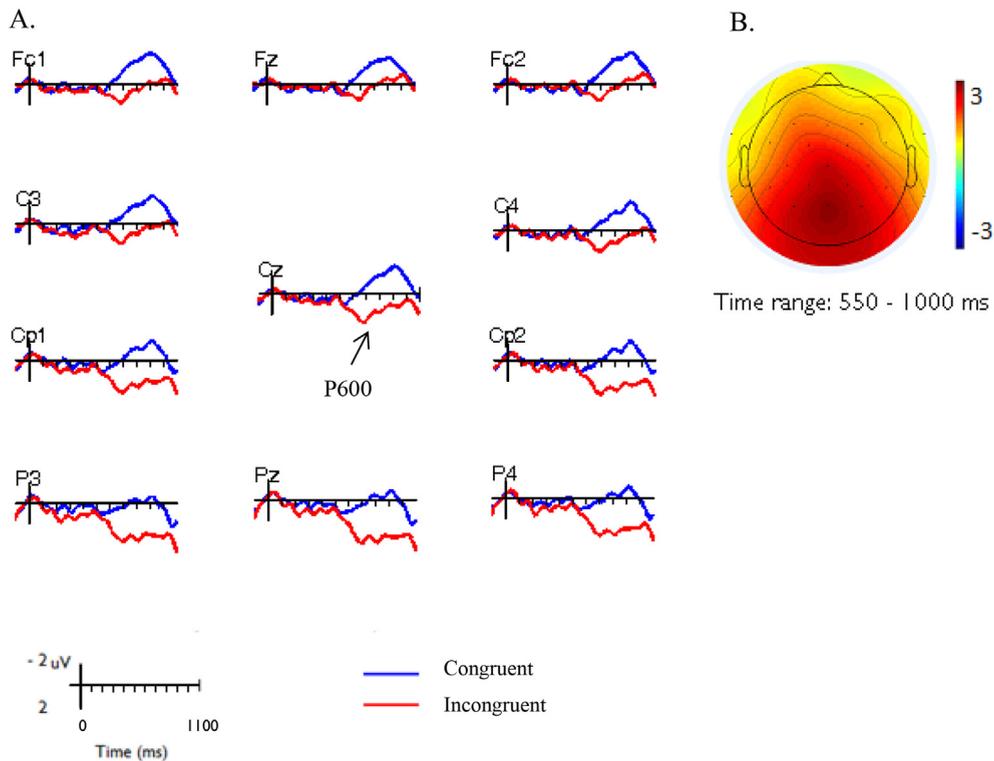
Fig. 4. Panel A shows grand average ERPs for congruent (blue line) and incongruent (red line) subcategorized prepositions. The onset of the preposition is at 0 ms. Panel B gives topographical information for the P600 (time range: 550–1000 ms) effects. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2.3. Difference wave analyses

To allow a direct comparison between the effects found for the LexP and SubP conditions, we 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 Fig. 6.

We compared the effects for the lexical and subcategorized prepositions 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 S9). In the second time window 300–550 ms also a main effect of preposition type was found (Table 8). In both time windows the amplitudes of the difference waveforms for lexical prepositions were more negative than those for subcategorized prepositions (cf. Fig. 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.

In addition to the time windows for the prepositions presented in Fig. 6, we 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 showing amplitude difference between two waves (Table 8). 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, we 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 Figs. 3 and 5 for nouns in LexP and SubP sentences, respectively (Table 12S).

4. 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. We based this hypothesis 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
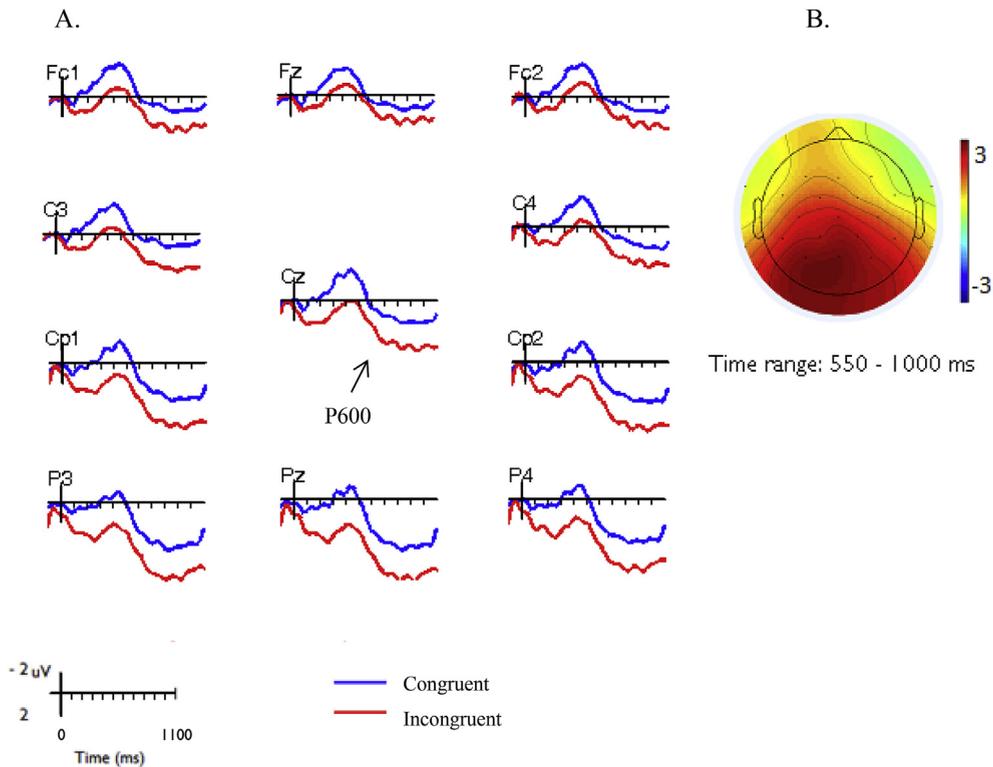
A.

B.

Fig. 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. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

theoretical research shows 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., Friederici et al., 2002; Kutas & Hillyard, 1980), 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; for a review on the late positive component see; Bornkessel-Schlesewsky & Schlesewsky, 2009). As such, we provide support for the view that (German) prepositions constitute a hybrid between functional and lexical categories.

4.1. Sentences with lexical prepositions

Two negative polarity shifts were elicited relative to the onset of lexical prepositions – 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, our hypothesis that lexical prepositions are processed like other lexical categories was supported. Less expected than the classical (mostly visual modality) N400, we 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, 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
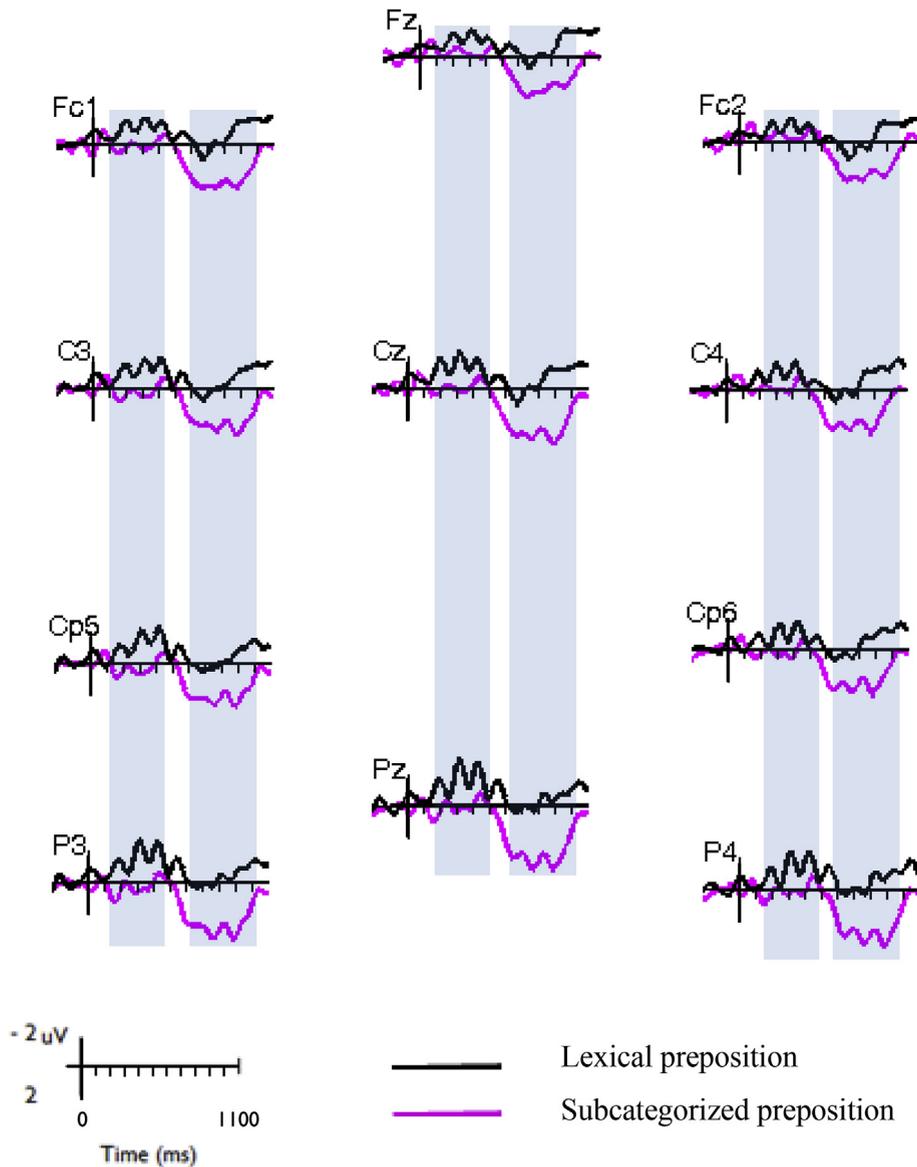
Fig. 6. Comparison of difference waveforms for the lexical preposition (black line) and for the subcategorized preposition (pink line). The shaded areas show time windows that were analyzed. The first shaded area includes two time windows, 100–250 ms and 300–550 ms while the second shaded area shows the latency of 550–1000 ms. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 8
Brief summary with estimated effect sizes and significance levels of the LMM statistics for the difference waveforms for at prepositions in LexP and SubP sentences (time windows: 300–550 ms and 550–1000 ms) and nouns (time window: 550–1000 ms) in LexP and SubP sentences. The full statistical model is given in the supplementary materials (Tables 9S, 10S & 11S).

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

Significance codes: '***' $p < 0.001$; '**' < 0.01; '*' < 0.05; '.' < 0.1.

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. Our finding of consecutive N200 and N400 effects for the lexical preposition can be related to these previous studies. In our 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* was 2,7 (on a scale from 1- very easy to 6- very difficult). The consecutive N200 and N400 effects observed in our experiment are thus similar to the negative effects reported by both Van Den Brink et al. (2001) and Connolly et al. (1990). In both of these studies processing effects (N200 and N400) were elicited because the critical word did not satisfy the initial acoustic analysis of a word-form as well as the word semantics predicted by the sentential context. In our 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 semantic and phonological word-form level; hence, the 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, most contexts can be highly constraining for specific prepositions and if this expectancy is not met, it affects processing.

As predicted for the noun in LexP sentences, we found an N400 effect in the incongruent condition with even distribution over the scalp. Although the 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, we 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 occurred 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. 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, incongruent LexP sentences, which did not contain (morpho)syntactic violations, elicited a P600 (or a late positivity) at the noun in our experiment. Traditionally, this component has been observed in response to (morpho)syntactic violations, however, it has been found to be sensitive to non-syntactic information as well as discussed in the introduction section (for a detailed review on P600 see Bornkessel-Schlesewsky & Schlesewsky, 2009; Swaab et al., 2012). The late positive effect found in LexP sentences follows the earlier negative effects elicited by the lexical preposition and the noun in these sentences. Subsequent N400–P600 patterns have been reported before as a correlate to semantic or thematic processing difficulties (e.g., Frisch & Schlesewsky, 2001; Hoeks et al., 2004; Roehm et al., 2007), to irresolvable argument-induced conflicts (Frenzel, Schlesewsky, & Bornkessel-Schlesewsky, 2011) and to agreement violations (Mancini, Molinaro, Rizzi, & Carreiras, 2011; Mancini, Massol, Duñabeitia, Carreiras, & Molinaro, 2018; Zawiszewski et al., 2016; Zawiszewski & Friederici, 2009). Similarly to Roehm et al. (2007) and Hoeks et al. (2004) who report P600 effects to syntactically correct sentences, our LexP sentences elicited a P600 although being syntactically valid. In contrast to Roehm et al. and Hoeks et al. the semantic processing conflict could be argued to be "more costly" in our sentences as the processing breaks down twice along the sentence, namely, first the dispreferred lexical preposition elicits an N400 and secondly the final noun does. The N400 elicited at two points during the processing of these sentences makes them quite clearly faulty and by the time the sentence is finished it is obvious that it cannot be successfully revised. The late positive effect that we find in these sentences cannot be related to syntactic problems (as there are no such). This positive effect could be interpreted as the result of processes related to global analysis of a sentence's well-formedness as argued by Roehm et al. (2007) and Frenzel et al. (2011). In line with their work, we suggest that the P600 found in our LexP sentence indicates a process classifying sentences as ill-formed.

4.2. Sentences with subcategorized prepositions

We found no negative components 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, overlaps 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 (P3a and P3b). In language studies, a P300 has been reported to occur around 300 ms and later (Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998; Osterhout and Holcomb, 1992; for a review on language-related P300 see Van Petten & Luka, 2012). P300 effects have been explained as reflecting "context updating" processes

(Donchin & Coles, 1988). This effect has been linked to disconfirmation of an expectation in a wide range of experiments. For example, a P300 was elicited when a noun phrase was anticipated, but instead a prepositional phrase was encountered (Osterhout and Holcomb, 1992). In our study, the occurrence of this positive effect to incongruent subcategorized prepositions could be related to disconfirmation of an expected/specific preposition. This expectation could have been caused by a strong bond between the verbs and (congruent) subcategorized prepositions. However, because our experiments were not specifically designed for examining a P300 effect, we restrain from making definitive conclusions regarding its interpretation in our experiment. Further studies manipulating stimuli with the aim of eliciting this component in the context of prepositions are necessary to better understand this effect.

A P600 effect emerged in relation to subcategorized prepositions. Recall from the introduction that P600 effects have been shown to occur in sentences that are ungrammatical, but also in correct sentences with a non-preferred syntactic structure (e.g., Friederici, 2011; Kaan, 2007; Kaan & Swaab, 2003; Osterhout et al., 1994). We interpret the P600 following the subcategorized prepositions as a response to a structural unexpectedness during parsing. We can relate this effect to parsing difficulties similar to those reported by Allen, Badecker, and Osterhout (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 sub-categorized 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). There were no early negative effects (E/LAN) correlated with the processing of incongruent subcategorized prepositions. The dispreferred rather than incorrect structures created by incongruent subcategorized prepositions are likely why we do not get early negative effects as a result of their processing.

A sentence-final P600 was also found following the nouns in SubP sentences. Similarly to the sentence-final P600 in LexP sentences, the P600 found to SubP sentences can be interpreted as a global evaluation of the sentence well-formedness. Roehm et al. (2007) and Frenzel et al. (2011) offer this interpretation when a P600 is preceded by an N400 effect as in their studies. In our case, it was not possible to establish the presence of an N400 preceding a P600 for the nouns in SubP sentences as, if present, this (or any other early effect) would have overlapped with the late positive effect found following the subcategorized prepositions. We think that the interpretation of a P600 as the marker of sentence well-formedness evaluation offered by Roehm et al. and Frenzel et al. can be applied here (as in the case of the LexP sentence-final P600).

4.3. Difference waveforms

To compare results of both types of sentences (LexP and SubP), we 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, not only the amplitudes but also the polarity of the effects are distinct – 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.

5. Conclusion

Our results 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. We 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 can be classified as a hybrid between lexical and functional categories.

Conflict of interest statement

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jneuroling.2019.100857.

References

Allen, M., Badecker, W., & Osterhout, L. (2003). Morphological analysis in sentence processing: An ERP study. *Language & Cognitive Processes, 18*(4), 405–430. https://doi.org/10.1080/01690960244000054.

Asbury, A., Gehrke, B., & Nouwen, R. (Vol. Eds.), (2008). *Syntax and semantics of spatial P: Vol.120*John Benjamins Publishing.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005.

Baker, M. C. (2003). *Lexical categories: Verbs, nouns and adjectives, Vol.102*Cambridge University Presshttps://doi.org/10.1016/j.jml.2007.12.005.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). lme4: Linear mixed-effects models using eigen and S4. R package version 1.1–7. Available at: https://cran.r-project.org/web/packages/lme4/index.html.

Biemann, C., Heyer, G., Quasthoff, U., & Richter, M. (2007). The Leipzig corpora collection-monolingual corpora of standard size. *Proceedings of Corpus Linguistic* 2007.

Bolinger, D. (1971). *The phrasal verb in English.* Cambridge, MA: Harvard University Press. https://doi.org/10.1017/S0008413100008409.

Bornkessel-Schlesewsky, I., & Schlesewsky, M. (2009). *Processing syntax and morphology: A neurocognitive perspective, Vol. 6.* Oxford University Press.

Botwinik-Rotem, I. (2004). *The category P features, projections, interpretation (doctoral dissertation).* Tel-Aviv University.

Brouwer, H., Fitz, H., & Hoeks, J. (2012). Getting real about semantic illusions: Rethinking the functional role of the P600 in language comprehension. *Brain Research, 1446*, 127–143. https://doi.org/10.1016/j.brainres.2012.01.055.

Brown, C. M., Hagoort, P., & Ter Keurs, M. (1999). Electrophysiological signatures of visual lexical processing: Open-and closed-class words. *Journal of Cognitive Neuroscience, 11*(3), 261–281.

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.

Chomsky, N. (1993). *Lectures on government and binding: The Pisa lectures (No. 9).* Walter de Gruyter.

Connolly, J. F., & Phillips, N. A. (1994). Event-related potential components reflect phonological and semantic processing of the terminal word of spoken sentences. *Journal of Cognitive Neuroscience, 6*(3), 256–266.

Connolly, J. F., Stewart, S. H., & Phillips, N. A. (1990). The effects of processing requirements on neurophysiological responses to spoken sentences. *Brain and Language, 39*(2), 302–318. https://doi.org/10.1016/0093-934X(90)90016-A.

Corver, N., & van Riemsdijk, H. (Vol. Eds.), (2001). *Semi-lexical categories: The function of content words and the content of function words: Vol.59*Walter de Gruyter.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009.

Diaz, M. T., & McCarthy, G. (2009). A comparison of brain activity evoked by single content and function words: An fMRI investigation of implicit word processing. *Brain Research, 1282*, 38–49. https://doi.org/10.1016/j.brainres.2009.05.043.

Donchin, E., & Coles, M. G. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences, 11*(3), 357–374. https://doi.org/10.1017/S0140525X00058027.

Ferree, T. C., Luu, P., Russel, G. S., & Tucker, D. M. (2001). Scalp-electrode impedance, infection risk, and EEG data quality. *Clinical Neurophysiology, 112*(3), 536–544. https://doi.org/10.1016/S1388-2457(00)00533-2.

Finke, M., Büchner, A., Ruigendijk, E., Meyer, M., & Sandmann, P. (2016). On the relationship between auditory cognition and speech intelligibility in cochlear implant users: An ERP study. *Neuropsychologia, 87*, 169–181. https://doi.org/10.1016/j.neuropsychologia.2016.05.019.

Fjaellingsdal, T. G., Ruigendijk, E., Scherbaum, S., & Bleichner, M. G. (2016). The N400 effect during speaker-switch—towards a conversational approach of measuring neural correlates of language. *Frontiers in Psychology, 7*.

Frenzel, S., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2011). Conflicts in language processing: A new perspective on the N400–P600 distinction. *Neuropsychologia, 49*(3), 574–579. https://doi.org/10.1016/j.neuropsychologia.2010.12.003.

Friederici, A. D. (1983). Children's sensitivity to function words during sentence comprehension. *Linguistics, 21*(5), 717–740. https://doi.org/10.1515/ling.1983.21.5.717.

Friederici, A. D. (2001). Syntactic aspects of language, neural basis of. In international encyclopedia of the social & behavioral sciences. https://doi.org/10.1016/B0-08-043076-7/03494-X.

Friederici, A. D. (2004). Event-related brain potential studies in language. *Current Neurology and Neuroscience Reports, 4*(6), 466–470.

Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiological Reviews, 91*(4), 1357–1392. https://doi.org/10.1152/physrev.00006.2011.

Friederici, A. D., Hahne, A., & Saddy, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research, 31*(1), 45–63. http://hdl.handle.net/11858/00-001M-0000-0010-ACA4-A.

Frisch, S., & Schlesewsky, M. (2001). The N400 reflects problems of thematic hierarchizing. *NeuroReport, 12*(15), 3391–3394. https://doi.org/10.1097/00001756-200110290-00048.

Gazzaniga, M. S. (Ed.). (1988). *Perspectives in memory research.* MIT Press.

Grimshaw, J. (1991). *"Extended projections", ms.* NY: Brandeis University.

Hagoort, P. (2008). The fractionation of spoken language understanding by measuring electrical and magnetic brain signals. *Philosophical Transactions of the Royal Society of London B Biological Sciences, 363*(1493), 1055–1069.

Hagoort, P., & Brown, C. (1994). Brain responses to lexical ambiguity resolution and parsing. In C. Clifton, L. Frazier, & K. Rayner (Eds.). *Perspectives on sentence processing* (pp. 45–81). Hillsdale, NJ: Erlbaum.

Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech: Semantic ERP effects. *Neuropsychologia, 38*(11), 1518–1530. https://doi.org/10.1016/S0028-3932(00)00052-X.

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes, 8*(4), 439–483. https://doi.org/10.1080/01690969308407585.

Haider, H. (2010). *The syntax of German.* Cambridge University Press.

Hoeks, J. C., Stowe, L. A., & Doedens, G. (2004). Seeing words in context: The interaction of lexical and sentence level information during reading. *Cognitive Brain Research, 19*(1), 59–73. https://doi.org/10.1016/j.cogbrainres.2003.10.022.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language & Cognitive Processes, 5*(4), 281–312. https://doi.org/10.1080/01690969008407065.

Jackendoff, R. (1973). In S. Anderson, & P. Kiparsky (Eds.). *The basic rules for prepositional phrases.* New York: Holt, Rinehart and Winston.

Jackendoff, R. (1977). *X'-Syntax: A study of phrase structure.* Cambridge, Mass: MIT Press.

Kaan, E. (2007). Event-related potentials and language processing: A brief overview. *Language and Linguistics Compass, 1*(6), 571–591. https://doi.org/10.1111/j.1749818X.2007.00037.x.

Kaan, E., & Swaab, T. Y. (2003). Repair, revision, and complexity in syntactic analysis: An electrophysiological differentiation. *Journal of Cognitive Neuroscience, 15*(1), 98–110.

Kim, A., & Osterhout, L. (2005). The independence of combinatory semantic processing: Evidence from event-related potentials. *Journal of Memory and Language, 52*(2), 205–225. https://doi.org/10.1016/j.jml.2004.10.002.

Kuperberg, G. R., Kreher, D. A., Sitnikova, T., Caplan, D. N., & Holcomb, P. J. (2007). The role of animacy and thematic relationships in processing active English sentences: Evidence from event-related potentials. *Brain and Language, 100*(3), 223–237. https://doi.org/10.1016/j.bandl.2005.12.006.

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621–647. https://doi.org/10.1146/annurev.psych.093008.131123.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203–205.

Lindstromberg, S. (2010). *English prepositions explained.* Amsterdam and Philadelphia: John Benjamins. https://doi.org/10.1075/z.157.

Littlefield, H. A. (2006). *Syntax and Acquisition in the prepositional domain: Evidence from English for fine-grained syntactic categories (doctoral dissertation).* Boston University.

MacWhinney, B. (2000). (3rd ed.). *The CHILDES Project: Tools for analyzing talk: The databaseVol. 2.* Mahwah, NJ: Lawrence Erlbaum Associates.

Makeig, S., Debener, S., Onton, J., & Delorme, A. (2004). Mining event-related brain dynamics. *Trends in Cognitive Sciences, 8*(5), 204–210. https://doi.org/10.1016/j.tics.2004.03.008.

Mancini, S., Massol, S., Duñabeitia, J. A., Carreiras, M., & Molinaro, N. (2018). Agreement and illusion of disagreement: An ERP study on Basque. *Cortex.* https://doi.org/10.1016/j.cortex.2018.08.036.

Mancini, S., Molinaro, N., Rizzi, L., & Carreiras, M. (2011). A person is not a number: Discourse involvement in subject–verb agreement computation. *Brain Research, 1410*, 64–76. https://doi.org/10.1016/j.brainres.2011.06.055.

Mätzig, S. (2009). *Spared syntax and impaired spell-out: The case of prepositions in broca's and anomic aphasia.* Doctoral dissertation, University College London.

Molinaro, N., Barber, H. A., & Carreiras, M. (2011). Grammatical agreement processing in reading: ERP findings and future directions. *Cortex, 47*(8), 908–930. https://doi.org/10.1016/j.cortex.2011.02.019.

Molinaro, N., Vespignani, F., & Job, R. (2008). A deeper reanalysis of a superficial feature: An ERP study on agreement violations. *Brain Research, 1228*, 161–176. https://doi.org/10.1016/j.brainres.2008.06.064.

Neeleman, A. (1996). PP-Complements in Dutch. In J. Camacho (Ed.). *Proceedings of WCCFL 14.* Stanford: CSLI Publications.

Neeleman, A. (1997). PP-complements. *Natural Language & Linguistic Theory, 15,* 89–137.

Neville, H. J., Mills, D. L., & Lawson, D. S. (1992). Fractionating language: Different neural subsystems with different sensitive periods. *Cerebral Cortex, 2*(3), 244–258. https://doi.org/10.1093/cercor/2.3.244.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*(6), 785–806. https://doi.org/10.1016/0749-596X(92)90039-Z.

Osterhout, L., Holcomb, P. J., & Swinney, D. A. (1994). Brain potentials elicited by garden-path sentences: Evidence of the application of verb information during parsing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(4), 786. https://doi.org/10.1037//0278-7393.20.4.786.

Ouhalla, J. (1999). *Introducing transformational grammar: From principles and parameters to minimalism.* Oxford University Press.

Pulvermüller, F., Lutzenberger, W., & Birbaumer, N. (1995). Electrocortical distinction of vocabulary types. *Electroencephalography and Clinical Neurophysiology, 94*(5), 357–370. https://doi.org/10.1016/0013-4694(94)00291-R.

R Development Core Team (2014). *R: a language and environment for statistical computing.* Vienna: R Foundation for Statistical Computing. Available online at: http://www.R-project.org/.

Rauh, G. (1993). On the grammar of lexical and non-lexical prepositions in English. In Zelinskiy-Wibbelt (Vol. Ed.), *99-150. Trends in cognitive sciences: Vol. 8,* (pp. 204–210). 5.

Roehm, D., Bornkessel-Schlesewsky, I., Rösler, F., & Schlesewsky, M. (2007). To predict or not to predict: Influences of task and strategy on the processing of semantic relations. *Journal of Cognitive Neuroscience, 19*(8), 1259–1274.

Rösler, F., Pechmann, T., Streb, J., Röder, B., & Hennighausen, E. (1998). Parsing of sentences in a language with varying word order: Word-by-word variations of processing demands are revealed by event-related brain potentials. *Journal of Memory and Language, 38*(2), 150–176. https://doi.org/10.1006/jmla.1997.2551.

Ruigendijk, E., Hentschel, G., & Zeller, J. P. (2016). How L2-learners' brains react to code-switches: An ERP study with Russian learners of German. *Second Language Research, 32*(2), 197–223. http://slr.sagepub.com/cgi/doi/10.1177/0267658315614614.

Segalowitz, S. J., & Lane, K. C. (2000). Lexical access of function versus content words. *Brain and Language, 75*(3), 376–389. https://doi.org/10.1006/brln.2000.2361.

Steinhauer, K., & Drury, J. E. (2012). On the early left-anterior negativity (ELAN) in syntax studies. *Brain and Language, 120*(2), 135–162. https://doi.org/10.1016/j.bandl.2011.07.001.

Svenonius, P. (2004). Adpositions, particles, and the arguments they introduce. https://doi.org/10.1075/la.108.08sve.

Swaab, T. Y., Ledoux, K., Camblin, C. C., & Boudewyn, M. (2012). Language-related ERP components. In S. J. Luck, & E. S. Kappenman (Eds.). *Oxford handbook of event-related potential components.* New York: Oxford University Press.

Tseng, J. L. (2000). *The representation and selection of prepositions.* Doctoral dissertation, University of Edinburgh.

Van Den Brink, D., Brown, C. M., & Hagoort, P. (2001). Electrophysiological evidence for early contextual influences during spoken-word recognition: N200 versus N400 effects. *Journal of Cognitive Neuroscience, 13*(7), 967–985.

Van Herten, M., Kolk, H. H., & Chwilla, D. J. (2005). An ERP study of P600 effects elicited by semantic anomalies. *Cognitive Brain Research, 22*(2), 241–255. https://doi.org/10.1016/j.cogbrainres.2004.09.002.

Van Petten, C., & Luka, B. J. (2012). Prediction during language comprehension: Benefits, costs, and ERP components. *International Journal of Psychophysiology, 83*(2), 176–190. https://doi.org/10.1016/j.ijpsycho.2011.09.015.

Viola, F. C., De Vos, M., Hine, J., Sandmann, P., Bleeck, S., Eyles, J., et al. (2012). Semi-automatic attenuation of cochlear implant artifacts for the evaluation of late auditory evoked potentials. *Hearing Research, 284*(1–2), 6–15. https://doi.org/10.1016/j.heares.2011.12.010.

Zawiszewski, A., & Friederici, A. D. (2009). Processing canonical and non-canonical sentences in Basque: The case of object–verb agreement as revealed by event-related brain potentials. *Brain Research, 1284*, 161–179. https://doi.org/10.1016/j.brainres.2009.05.099.

Zawiszewski, A., Santesteban, M., & Laka, I. (2016). Phi-features reloaded: An event-related potential study on person and number agreement processing. *Applied PsychoLinguistics, 37*(3), 601–626. https://doi.org/10.1017/S014271641500017X.

Zwarts, J. (1997). Lexical and functional properties of prepositions. *Lexikalische und grammatische Eigenschaften präpositionaler Elemente. Linguistische Arbeiten, 371,* 1–19.