GLOSSA psycholinguistics

Kharaman, M., Czypionka, A., & Eulitz, C. (2025). Event-related potentials and oscillatory brain activity reflect a complex interplay of syntactic, semantic and pragmatic information during the processing of German discourse particles. *Glossa Psycholinguistics*, 4(1): 11, pp. 1–37. DOI: https://doi.org/10.5070/G601121312

eScholarship
University of California

Event-related potentials and oscillatory brain activity reflect a complex interplay of syntactic, semantic and pragmatic information during the processing of German discourse particles

Mariya Kharaman*, University of Konstanz, DE, mariya.kharaman@uni-konstanz.de
Anna Czypionka*, University of Konstanz, DE, anna.czypionka@uni-konstanz.de
Carsten Eulitz, University of Konstanz, DE, carsten.eulitz@uni-konstanz.de
*****Share first authorship.

Discourse particles are little words that provide non-at-issue content to sentences, reshaping the illocutionary force of an utterance. Among them, question-sensitive discourse particles (QDiPs), like German *denn*, are subject to a number of interacting syntactic, semantic and pragmatic licensing constraints, offering a unique window into language processing at the interfaces. We present EEG data on the processing of QDiPs in different types of interrogatives (eliciting either syntactic/semantic or pragmatic QDiP licensing), along with QDiPs in declaratives (i.e., unlicensed QDiPs resulting in ill-formed structures). The analysis of event-related potentials shows an increased negativity for QDiPs relative to a non-QDiP baseline in the P300/N400 time window; this is more pronounced for unlicensed QDiPs (in declaratives) than licensed QDiPs (in interrogatives). In the P600 time window, QDiPs elicit more positive-going curves than non-QDiPs, with this pattern wearing off for licensed, relative to unlicensed, QDiPs at later timepoints. Time-frequency analysis of the same EEG data reveals increased theta-band activity for non-QDiPs relative to QDiPs. We interpret the lower theta-band activity for QDiPs as reflecting the fact that QDiPs contribute non-at-issue meaning, but not at-issue meaning. Taken together, our findings showcase different aspects of QDiP processing; ranging from ERP correlates for straightforward licensing violations (late P600) and for increased processing cost during successful licensing (early P600) to oscillatory reflections of the 'semantic weakness' of discourse particles (lower theta-band activity). The two types of EEG analysis complement each other and tap into different aspects of language processing.

1. Introduction

Discourse particles in German are little words, like *bloß, schon, denn*, that are peppered throughout daily communication. These discourse particles (DiPs) reshape the illocutionary force of an utterance, adding “flavour” to sentences by providing non-at-issue content (in addition, each DiP has a non-DiP counterpart, which, unlike the DiP, adds semantic at-issue content). The exact meaning of DiPs can change with clause type, with some DiPs only occurring in declaratives or interrogatives. DiPs that only occur in questions are question-sensitive DiPs or QDiPs (e.g., *denn* or *schon*). QDiP licensing is characterized by a number of interacting syntactic, semantic and pragmatic characteristics and constraints; together, these constraints establish a (potentially long-distance) dependency. This makes QDiP licensing a very informative phenomenon for studying sentence processing at the interfaces, all the more so because different complex licensing processes are triggered by a single word (i.e., the QDiP).

Here, we will provide a quick overview of the details of QDiP licensing constraints, followed by a round-up of the (still limited) available literature on QDiP processing. We will then present the results of an EEG study. The aim of our study is to establish the electrophysiological correlates of QDiP licensing and licensing violations in event-related potentials and time-frequency responses.

1.1 Background

1.1.1 Theoretical background and behavioral findings: DiPs and QDiPs

Discourse particles, the “little words” at the center of this article, always have two readings. While one reading refers to the discourse particle, the other reading refers to its counterpart. The counterpart reading provides semantic at-issue content. The DiP, on the other hand, is “semantically weak”, providing no semantic at-issue content. Instead, it provides non-at-issue content (Potts, 2007), reshaping the illocutionary force of the utterance.[1]

DiPs are clause-sensitive, meaning that they are restricted to a particular clause type in their DiP reading, but not in their counterpart reading. In the following, we are concerned with the question-sensitive discourse particle (QDiP) *denn*, which is restricted to interrogatives. (In its counterpart reading, *denn* is a connective and can only occur at the beginning of a main clause. Due to this, *denn* is not ambiguous between its QDiP and counterpart readings in sentence context. This makes it suitable for our investigation, in contrast to other QDiPs, like *schon*, which allow for ambiguity between QDiP and counterpart readings in the same sentence positions).

[1] In other descriptions, DiPs contribute to the use-conditional meaning, but not to the truth-conditional meaning, of a sentence (Gutzmann, 2013, 2009; Kratzer, 1999, 2004; McCready, 2012; Zimmermann, 2004), or to expressive, but not descriptive, content (like epithets or expressive attributive adjectives; following Potts 2007, these two levels of meaning are separate).

The contribution of the QDiP *denn* is to link the content of a question to the previous discourse context (see König, 1977; Thurmair, 1991; see also Csipak & Zobel, 2016; Gutzmann, 2015; Theiler, 2020, for different formalizations). For illustration, consider the following sentence:

(1)

Was	hat	der	Peter	(denn)	gesagt?
What	has	the	Peter	QDIP	said

What did Peter (DENN) say?

Without *denn*, the question corresponds to the literal English translation, being a straightforward information-seeking question. Adding *denn*, however, implies that the question is linked to the preceding conversation context and that the speaker expects the addressee to know the answer to the question.

For this reason, the QDiP *denn* is pragmatically infelicitous in a number of sentence environments. Apart from being obviously infelicitous in declaratives without a [+Q] licenser (see (2)), it is also infelicitous in echo questions (see (3)), which are not truly interrogative. Furthermore, *denn* is also infelicitous in out-of-the-blue questions, where there is no shared context between speaker and addressee yet (Bayer, 2012; Grosz, 2005; Wegener, 2002) (see (4)).

(2)

Peter	hat	(*denn)	nichts	gesagt.
Peter	has	QDIP	nothing	said.

'Peter said nothing.'

(3)

Peter	hat	*was*	(*denn)	gesagt?!
Peter	has	what	QDIP	said

'Peter said *what*?!'

(4) [On approaching a stranger in the street:]

Entschuldigen	Sie	bitte,	wie	spät	ist	es	(*denn)?
Excuse	you	please	how	late	is	it	QDIP

'Excuse me, do you have the time?'

Successful QDiP licensing in interrogatives is subject to a number of licensing constraints with particular characteristics. These constraints are described in greater detail in Bayer & Obenauer (2011), Bayer et al. (2016), and Romero (2017); here, we only give a quick overview.

Syntactic licensing constraints demand that the QDiP must be in an interrogative local environment, allowing local feature agreement between interrogative Force and the QDiP. QDiP licensing across clause boundaries is not possible, unless the *wh*-element originates in the same clause as the QDiP (see Bayer et al. 2016, and references therein.). Semantic licensing constraints demand that the QDiP be licensed by a sister *v*P that is a question (see Czypionka et al. 2021; Romero 2017).

Both syntactic and semantic licensing constraints lead to the prediction that QDiPs should be licensed in interrogatives as long as they occur on the path of the *wh*-chain (see (5) for a *wh*-word and QDiP occurring in the same clause at the surface, and (6) for a *wh*-word being extracted from the clause containing the QDiP). In contrast, QDiPs should not be licensed in interrogatives when they are not positioned on the path of the *wh*-chain (7); the *wh*-word originates in the root clause, while the QDiP is positioned in the subordinate clause). In declaratives, there is no *wh*-word and no question, so QDiPs cannot be licensed in declaratives, making QDiP-containing declaratives like (8) ill-formed.

(5) Wer hat (denn) gesagt, dass der Türsteher den Musiker abweisen soll?
Who has QDiP said that the bouncer the musician turn.away should
'Who (QDiP) said that the bouncer should turn away the musician?'

(6) Wen hast du gesagt, dass der Türsteher (denn) abweisen soll?
Who.ACC have you said that the bouncer QDiP turn.away should
'Who did you say that the bouncer should (QDiP) turn away?'

(7) Wer hat gesagt, dass der Türsteher den Musiker (*denn) abweisen soll?
Who has said that the bouncer the musician QDiP turn.away should
'Who said that the bouncer should (QDiP) turn away the musician?'

(8) Peter hat (*denn) gesagt, dass der Türsteher den Musiker (*denn) abweisen
Peter has QDiP said that the bouncer the musician QDiP turn.away
soll.
should
'Peter (QDiP) said that the bouncer should (QDiP) turn away the musician.'

Recently, the semantic analysis has been relaxed to allow for an additional pragmatic licensing mechanism. This additional licensing mechanism allows *denn* to be licensed indirectly by the pragmatics of its sister in subordinate clauses, even if it is not of the interrogative question type, as long as the question-under-discussion (QUD) implies the existence of focus alternatives (Czypionka et al., 2021; Romero, 2017). Following this account, a sentence like (7) would not meet syntactic/semantic licensing constraints, but would still remain interpretable, thanks to pragmatic licensing mechanisms.

In general, the predictions from the three different types of licensing mechanisms are borne out: Czypionka et al. (2021) report low acceptability ratings and increased reading times for *denn* in declaratives (8) compared to interrogatives (5). As predicted by syntactic and semantic licensing constraints, clause boundaries between *denn* and interrogative Force lead to a drop in ratings (lower ratings for (7) than for (5)), unless the *wh*-element is extracted from the embedded clause (6) (see also Bayer 1991; Bayer et al. 2016, for earlier parallel reports). However, ratings for *denn* with out-of-reach licensers (7) do not drop to values for ungrammatical sentences like (8), leading to the conclusion that these sentences are dispreferred relative to (5), but ultimately interpretable thanks to the pragmatic licensing mechanism proposed by Romero (2017) (see Czypionka et al. 2021, for an in-depth discussion).

1.1.2 Psycholinguistic background: QDiP processing

While DiPs are the topic of a wide theoretical literature, there is little existing research on the processing of DiPs, in general, or QDiPs, in particular. For DiPs, Dörre and colleagues (Dörre, 2018; Dörre et al., 2018) show that DiPs lead to increases in reading times relative to their non-DiP counterparts in string-identical sentences when readings are disambiguated via context. Their findings suggest that processing the non-at-issue content added by the "semantically weak" DiP is linked to increased processing cost. Czypionka et al. (2021) report the results of acceptability rating studies (mentioned above) and self-paced reading time studies on QDiP licensing and licensing violations. They find that relative to a non-QDiP baseline, QDiPs with absent licensers (as in (8)) lead to decreases in acceptability ratings and to longer reading times. Well-licensed QDiPs (like (5) or (6)), in contrast, elicit no drop in ratings relative to the non-QDiP baseline, and to mild increases in reading time only for the most complex structures (6). As mentioned above, QDiPs with syntactically inaccessible licensers (like (7)) lead to only a mild drop in ratings, and show no increase in reading time relative to QDiPs in the same position with accessible licensers (6). As outlined above, the authors interpret their findings as reflecting an alternative pragmatic licensing strategy for QDiPs with syntactically inaccessible licensers.

1.1.3 Neurolinguistic background: ERPs

To our knowledge, the experiment presented here is the first attempt to monitor the neurolinguistic correlates of QDiP licensing and licensing violations.[2] We therefore have to formulate our expectations and predictions based on the existing literature on behavioral investigations of QDiP processing (see above) and on neurolinguistic literature on similar phenomena.

A similar and comparatively well-researched phenomenon in the neurolinguistic literature is the licensing of negative polarity items (NPIs), like *ever*.[3] Like QDiPs, NPIs are subject to a number of licensing constraints uniting syntactic, semantic and pragmatic aspects. To be licensed, an

---

[2] An earlier ERP analysis of our data was published in a volume of conference proceedings as Czypionka et al. (2022). In comparison to this earlier publication, the analysis presented here provides additional findings for the ERP results, and adds the results of a time-frequency analysis. For the sake of readability, we will not repeat the outcomes of the earlier ERP analysis here as if it were a different study.

[3] There is no doubt that both licensing phenomena differ in many ways. At the same time, there are more detailed theoretical descriptions and more experimental work on NPI licensing than on QDiP licensing at this point. We restrict the discussion of parallels and differences to a minimum here, only focusing on the issues that are relevant for the current study.

NPI must appear in a non-veridical environment (see, e.g., Chierchia 2006; Giannakidou 2006, 2011; Hoeksema 2012; Krifka 1995; Ladusaw 1996; Laka 1994; Penka & Zeijlstra 2010, for more details). Many experimental studies achieve this by placing the NPI in the scope of a licenser specified for [+NEG]; for overt negation, this means that the licenser c-commands the NPI.

In sum, despite obvious differences, both phenomena (QDiP and NPI licensing) show certain parallels, in that they involve a dependency between a licenser (specified as [+Q] for QDiPs, and [+NEG] for NPIs) and a licensee in a certain syntactic configuration. In both cases, licensing is attested when the licenser locally c-commands the licensee.

Relative to licensed NPIs, unlicensed NPIs have been reported to elicit an enhanced P600[4] (Steinhauer et al. 2010; Xiang et al. 2009, for English),[5] but also an enhanced N400[6] (Shao & Neville 1998, for English; Saddy et al. 2004, for German; Yurchenko et al. 2013, for Dutch). Many studies report a biphasic N400-P600 pattern (Xiang et al. 2016, for English; Drenhaus et al. 2005, 2007; Liu et al. 2019, for German), with the N400 weaker for intrusive licenser conditions than for absent licenser conditions (Drenhaus et al. 2005).[7] Investigating the effect of different types of licensers, Xiang et al. (2016) found an enhanced N400 and P600 for unlicensed

---

[4] The P600 is a slow positive shift with a peak amplitude (if observed) about 600 ms post stimulus onset (Hagoort et al., 1993, 1999; Osterhout & Holcomb, 1992, 1993). Initially interpreted as a syntactic processing marker reflecting the detection of syntactic anomaly or the resolution the syntactic ambiguity, the interpretation of the P600 component has expanded, including processes of syntactic (Kaan et al., 2000) as well as semantic-thematic integration (Kuperberg et al., 2003), syntactic priming (Ledoux et al., 2007) and discourse-related interpretative processes (Regel et al., 2011a). For a revision of a functional role for the P600 component in language comprehension, see Brouwer et al. (2012).

[5] Yanilmaz & Drury (2018) also report enhanced LAN and P600 components for Turkish in unlicensed vs. licensed NPI conditions. However, these effects were elicited on sentence-final verbs, not the NPIs, making a 1:1 transfer of expectations difficult for our article.

[6] The N400 is a negative deflection in the EEG waveform peaking at around 400 ms post stimulus onset, first described by Kutas & Hillyard (1980). In the context of language processing, it has been linked to increased processing cost due to a number of factors, the uniting aspect being increased cost of lexical access (Brouwer et al., 2012), or, more neutrally put, “the relative efficiency in processing stimulus or word properties relative to the preceding context” (Alday & Kretzschmar, 2019, p.3). Related to this, N400 amplitude is influenced by a host of properties, including a word’s frequency, pre-activation via priming or context-based predictions, and its fit with the sentence and wider discourse context in terms of semantics, plausibility and world knowledge (see Baggio & Hagoort 2011; Kutas & Federmeier 2011 for thorough reviews and further references, and Hagoort 2013 for its relation to lexical access and semantic unification costs in sentence processing).

[7] A particular focus in the NPI processing literature is on ‘intrusive’ licensing. This happens when a potential [+NEG] licenser is present, but inaccessible (i.e., not in a position c-commanding the NPI), leading to higher rates of acceptance and lower processing cost for structures with syntactically inaccessible licensers than with absent licensers (see Drenhaus et al. 2005; Parker & Phillips 2016; Saddy et al. 2004; Vasishth et al. 2008; Xiang et al. 2009, 2013; see Parker & Phillips 2016; Yanilmaz & Drury 2018, for in-depth discussions). For QDiPs, earlier findings also show higher acceptability of structures with syntactically inaccessible licensers, relative to absent licensers (Czypionka et al., 2021), at first glance reminiscent of intrusive NPI licensing. Unlike the structures eliciting intrusive NPI licensing, however, these findings are robust even when ratings are elicited without time pressure; suggesting that for QDiPs, an alternative pragmatic licensing strategy is a more likely explanation than an error in processing.

NPIs, relative to licensed NPIs. Interestingly, the effects of explicit licensers (like *no* or *few*) differed from those of implicit licensers (emotive predicates, like *to be surprised*) in topography and amplitude, with an enhanced P600 for implicitly licensed NPIs, relative to explicitly licensed NPIs. The authors take this latter finding to reflect the enhanced processing cost associated with additional semantic-pragmatic processing in the latter condition.

In the absence of previous ERP studies on QDiP processing, we base our expectations on these findings from the ERP literature on NPIs. Taken together, the N400 and P600 time windows are the most promising candidates for finding correlates of QDiP processing. In addition to expecting visible reflections of violations of licensing constraints, we will also check for enhanced processing cost during ultimately successful processing of well-formed structures, elicited by the workload of checking multiple licensing constraints, resorting to different licensing strategies, and processing non-at-issue content.

1.1.4 Neurolinguistic background: Oscillatory brain activity and time-frequency analyses

In addition to more traditional types of ERP analysis, the analysis of oscillatory brain activity using time-frequency analysis is rapidly gaining in popularity. This analysis allows researchers to gain extra information about underlying processes that may not surface in ERP correlates. As the time-frequency analysis is performed for each trial separately before averaging, information which is usually canceled out due to the averaging of the trials is still accessible.

A number of studies have attempted to define the ‘functionality’ of different frequency bands with respect to different aspects of language and the cognitive tasks related to their processing (for a general overview, see Iaia et al. 2021). The established frequency bands are delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz) and gamma (above 30 Hz). The potentially interesting bands for our experiment are theta, alpha and beta.[8] Beta oscillations are related to stimulus novelty (Haenschel et al., 2000; Momsen & Abel, 2021), unification operations (Bastiaansen & Hagoort, 2006) or distinctive feature detection (Eulitz & Obleser, 2007). Attentional processing and working memory load can be detected in the alpha frequency band (Bastiaansen & Hagoort, 2006). Theta oscillations are associated with syllabic rhythm (Giraud & Poeppel, 2012; Gross et al., 2013), lexico-semantic properties of words in isolation and their integration in the text, as well as verbal memory load involved in reanalysing the sentence (Bastiaansen & Hagoort, 2006; Bastiaansen et al., 2005, 2008; Hald et al., 2006; Maguire et al., 2021). Increases in theta power can also reflect higher lexical retrieval and integration costs related to semantic violations as well as some grammar

[8] Delta, associated with the perception of the intonation contour (Giraud & Poeppel, 2012) or prosodic parsing (Ghitza, 2011) is not informative for our experimental design. The gamma band (rapid phonemic transitions detection, Ghitza; Giraud & Poeppel) was not investigated, due to low-pass filtering.

violations (e.g., gender and number) (Bastiaansen et al., 2002; Hald et al., 2006). Using the violation paradigm in an MEG experiment, Pu et al. (2020) also found a theta power increase for semantically incorrect sentence endings, concurring with previous findings. Interestingly, no theta power increase was found for semantically correct but syntactically incorrect sentence endings (number violation) compared to semantically and syntactically correct ones. The authors argue that a theta power increase does not reflect general sentence information processing, but rather lexical-semantic processing. In addition, theta power was also shown to be sensitive to the lexical-semantic properties of individual words in the sentence: Closed class words are reported to evoke less enhancement compared to open class words (Bastiaansen & Hagoort, 2006; Bastiaansen et al., 2005, 2008).

While these findings certainly illustrate the many different facets of linguistic processing reflected in oscillatory activity, they do not allow us yet to formulate clear predictions for correlates of QDiP processing. We will, therefore, offer an exploratory analysis, in the hope of adding to the growing literature on oscillatory brain activitiy in language processing. At the same time, the existing literature makes us confident that activity in the theta band may prove a good starting point, given its relevance for the processing of closed-class, relative to open-class, words (arguably, DiPs can be considered closed-class words).

1.2 Research questions and predictions

The aim of our study is to characterize the electrophysiological correlates of QDiP processing in sentence comprehension, using both ERP and oscillatory analysis. The first research question concerns the correlates of QDiP licensing violations. The second research question concerns the correlates of successful licensing in well-formed sentences, both for syntactically accessible and inaccessible licensers.

Based on the neurolinguistic literature on NPI processing outlined above, we expect effects of QDiP licensing and licensing violations to become visible during two time windows, namely, the N400 and P600 time windows, relative to a non-QDiP baseline in otherwise identical sentences. Due to the differences between NPIs and QDiPs, more specific predictions are difficult to formulate at this point. However, we tentatively speculate that outright licensing violations (i.e., QDiPs in declaratives) may elicit biphasic ERP responses. Successful QDiP licensing, on the other hand, might be expected to not lead to an N400 increase, while still eliciting an enhanced P600, relative to the baseline (based on the idea that all constraint checking processes can be assumed to increase the workload for sentence unification operations). In addition, amplitudes, latencies and topographies may differ between licensed and unlicensed QDiPs, reflecting the qualitative difference between processing a striking licensing violation for the latter, but merely checking a number of complex interacting constraints for the former.

In the oscillatory brain activity, we could expect theta power increases for QDiPs without licensers or with inaccessible licensers, based on their low predictability in non-licensing sentence contexts (Hald et al., 2006; Li et al., 2017; Pu et al., 2020). On the other hand, theta power increases have also been associated with open-class, relative to closed-class, words (Bastiaansen et al., 2005). This might, in turn, lead to an attenuation of theta activity for QDiPs.[9]

Based on the literature outlined above and given the nature of our stimuli, we make two predictions. First, given the costs of QDiP sentence integration dependent on the accessibility of its licenser, we predict an enhanced theta power for the QDiPs with an absent or inaccessible licenser. Second, as the theta power response has been also shown to reflect lexico-semantic word class, we expect a higher theta power increase for non-QDiP baseline conditions, relative to the closed class QDiP *denn*.

2. Materials and methods

2.1 Language materials, experimental design and stimulus presentation

2.1.1 Description of language materials and example stimuli

The language materials consisted of 42 item sets with eight conditions each. An example of a typical item set is given in **Table 1**.

Sentences consisted of either simple main clauses or short main clauses followed by an embedded subordinate clause. Our stimulus design is a full cross of three different factors (two levels each). The first factor is DIP, indicating whether a sentence contains the QDiP *denn* or the non-QDiP *jetzt* ('now'). Unlike *denn*, *jetzt* is grammatical in all sentences. The second factor is POSITION, indicating whether *denn* (or *jetzt*) is positioned in the root clause or in the subordinate clause. The third factor is CLAUSE TYPE, indicating whether the sentence is interrogative or declarative. All embedding verbs were verbs of saying, meaning, etc.

All sentences with *denn* in declaratives are ill-formed, while sentences with *denn* in the interrogative root clauses are well-formed. *Denn* in the subordinate clause of interrogatives is not syntactically well-formed, but can be interpreted via pragmatic licensing (in Czypionka et al, 2021, these sentences were not rejected as unacceptable, but rather rated as slightly less acceptable than perfectly well-formed interrogatives with *denn* in the root clause).

[9] We also considered beta activity during our exploratory analysis, since QDiP licensing and licensing violations should affect unification. For one comparison only (interrogatives in root clauses), we found a very weak difference in beta activity. This does not allow a well-motivated interpretation. Monte-Carlo cluster-based permutation tests that we used for TF analysis need to rely more heavily on pairwise comparisons than ERP analysis, so they are not ideal for analysing reflections of complex unification processes, as opposed to lexical differences, in our experiment – see 2.1.1.1. For the sake of readability, we omit an in-depth report in this article.

Table 1: A representative example of one item in all eight stimulus conditions. Each example sentence illustrates both levels of DIP with identical clause types and position, mirroring the comparisons in the data analysis.

(A) interrogative, DiP in root clause (root-interrogative)

Wer hat den Kuchen aus der Bäckerei denn / jetzt aufgegessen?
Who has the cake from the bakery QDiP / nonQDiP up.eat.part
'Who ate the cake from the bakery?'

(B) interrogative, DiP in subordinate clause (subordinate-interrogative)

Wer hat gesagt, dass die Oma den Kuchen *denn / jetzt aufessen muss?
Who has said that the granny the cake QDiP / nonQDiP up.eat must
'Who said that Granny has to eat the cake?'

(C) declarative, DiP in root clause (root-declarative)

Robert hat den Kuchen aus der Bäckerei *denn / jetzt aufgegessen.
Robert has the cake from the bakery QDiP / nonQDiP up.eat.part
'Robert ate the cake from the bakery.'

(D) declarative, DiP in subordinate clause (subordinate-declarative)

Robert hat gesagt, dass die Oma den Kuchen *denn / jetzt aufessen muss.
Robert has said that the granny the cake QDIP / nonQDiP up.eat must
'Robert said that Granny has to eat the cake.'

2.1.1.1 Experimental design and data interpretation

Our experimental design allows us to interpret the resulting data and to control for potential confounds introduced by the factors manipulated. For each of the four conditions with the QDiP *denn*, the corresponding condition with the non-QDiP *jetzt* provides a baseline, allowing us to directly compare the signals elicited by QDiP processing, relative to general sentence processing. The baseline conditions are identical to the QDiP conditions in clause type and in the position of the critical word. In this way, we can avoid potential confounds: Any effects of clause type and/or position that affect both QDiPs and non-QDiPs should only reflect general sentence processing, not QDiP licensing in particular (see, e.g., Felser et al. 2003; Fiebach et al. 2001, 2002; Gouvea et al. 2010; Kaan et al. 2000; Phillips et al. 2005, for processing correlates of clause type differences in *wh*-fronting languages, and Tomasello 2023; Tomasello et al. 2022, for examples and an overview of neurolinguistic processing correlates for different speech acts). In turn, any effects of clause type and/or position that interact with DiP type can be argued to reflect processes that are specifically related to QDiP licensing in different clause types and positions.[10]

Main effects of DiP type (i.e., differences between *denn* and *jetzt* that affect all clause types/positions in a similar way) could reflect either strong effects of QDiP licensing, or purely lexical differences between these two words. We will discuss them accordingly. We assume that purely lexical differences will mainly affect earlier time windows or N400 amplitude, but not integration-related P600 effects (see, e.g., Hasting & Kotz 2008).

2.1.2 Stimulus presentation

Stimuli were presented in the center of the screen word-by-word, apart from arguments in the embedded clause, which were presented as full DPs (i.e., article and noun on one screen). Sentences were preceded by a 500 ms asterisk, followed by a 200 ms blank screen. Each chunk was presented for 750 ms, with an ISI of 150 ms. After 20% of the sentences, we asked for a grammaticality judgment, in order to monitor participants' attention and provide a task. All participants saw all stimuli. During the experiment, sentences were interspersed with 252 unrelated filler sentences. To avoid overly long recording sessions, recordings were split into two separate sessions of equal length, conducted on different days. Each session lasted about 45 minutes. To minimize the effects of potential habituation, the stimulus material was split into two lists that were carefully balanced for conditions and items. Half of the participants saw the first list in the first session and the second list in the second session. For the other half of the participants, the order of the lists was reversed. Stimuli in each list were pseudorandomized for each participant. The mean time between sessions was 7.2 days (min = 4 days, max = 16 days).

---

[10] All results will be reported as a comparison between the *denn*-condition and its corresponding *jetzt*-condition, with both words occurring in the same clause type and condition. An anonymous reviewer was concerned that the comparison between two different lexical items (*denn* and *jetzt*) may introduce a confound of DiP type and lexical differences. We are confident that our experiment design is sound and that a direct comparison of *denn* and *jetzt* is actually necessary to arrive at interpretable ERP data. Having a non-QDiP lexical item as the baseline avoids the confounds outlined above in the main text. While participants will be processing the word *jetzt* in the baseline condition and integrating it into the sentence context, they will not (a) attempt to establish a dependency with a local clause-initial [+wh]-element or *wh*-trace; (b) in case the *wh*-trace is missing, attempt interpretation via complex pragmatic QDiP licensing; (c) in case there is no question meaning to be found, realize that the QDiP is uninterpretable and the sentence is ill-formed. Since data analysis will involve a hierarchical resolution of interactions of clause type, DiP type and position, this design allows us to tease apart results reflecting mere lexical differences and results reflecting the particular effects of clause type and position on QDiP processing. To this end, we will not be offering a direct comparison of, e.g., *denn* in declaratives and interrogatives; this type of analysis would not get rid of the confounds and would run counter to our design as outlined in the main text. – As another editor noted, a similar concern might be voiced about different sentence polarities in the NPI literature. We agree that this point is worthy of further discussion, but this would be beyond the scope of the current article.

2.2 Participants

35 participants were tested (14 male, 21 female, mean age = 24.5 years, sd = 3.3). Participants were recruited via the SONA systems database of Konstanz University. All participants had normal or corrected-to-normal vision. They reported no history of psychological or neurological illness. Participants were right-handed, following the Edinburgh handedness scale (Oldfield, 1971). All participants were monolingually raised native speakers of German. Data from four participants were removed during data preprocessing and are not considered in the data analysis and the results; three due to strong alpha waves, and one due to strong muscle activity in at least one of the two sessions. For the remaining participants, the mean rate of wrong answers was 18.5% for the critical conditions, and 22.6% for the whole experiment.[11]

2.3 Procedure

The EEG was recorded with 61 Ag/AgCl sintered ring electrodes attached to an elastic cap (EasyCap, Herrsching) and connected to an Easy-Cap Electrode Input Box (EiB32). Electrodes were positioned in the equidistant 61-channel arrangement provided by EasyCap (see http://easycap.brainproducts.com/e/electrodes/13M10.htm for electrode layout). Eye movements were monitored by recording the electrooculogram (IO1, IO2, Nz). The ground electrode was located on the right cheek.

3. ERP analysis

3.1 Data preparation and analysis

3.1.1 Data preprocessing

Data were processed using the Brain Vision Analyzer 2 software (Brain Products, Gilching). We began data preparation with a visual raw data inspection, manually removing time windows including strong visible artefacts and breaks. This was followed by an ICA blink correction, using the Slope Algorithm for blink detection, followed by visual inspection to monitor successful blink correction. Next, data were filtered (low cutoff 0.5 Hz, high cutoff 40 Hz, 50 Hz notch filter). For filtered data, topographic interpolation via triangulation was performed for channels that showed long stretches of noisy data. Interpolation was only performed for electrodes with at least three surrounding non-interpolated electrodes (two for electrodes on the outermost ring); for these electrodes, it was performed for the whole duration of the experiment. After interpolation, all electrodes were re-referenced to average reference. An Automatic Raw Data Inspection was performed for the re-referenced data (maximal allowed voltage step: 50 µV/ms; maximal allowed

---

[11] Responses to the pragmatic licensing condition *interrogative-subordinate-denn* (B) were counted as 'wrong' when participants rated the sentences as acceptable, and 'right' when they rejected them, coding responses in line with syntactic well-formedness rather than expected overall acceptability.

difference: 100 μV/ 200 ms; minimal/maximal allowed amplitudes 200 μV/ –200 μV; lowest allowed activity: 0.5 μV/ 100 ms) before segmentation. We defined the beginning of segments as 200 ms before stimulus onset and the end as 850 ms after stimulus onset. A baseline correction was performed for the 200 ms before stimulus onset.

On average, 1.07% of the segments were removed from the dataset. For two participants, the number of segments in one condition was 38 or higher; for the remaining participants, the number of segments was 40 or higher.

3.1.2 Selection of time windows

We defined the time windows for further data analysis using the data-driven approach reported by Tomasello et al. (2022). First we calculated the root mean square waveform across all conditions, subjects and electrodes. There we identified local maxima in the latency range of interest (later than 300 ms after word onset). Around these local peaks, we defined the full width at half maximum relative to the local minima in the neighborhood. This method led to the identification of four time windows with significant influences of discourse particles: TW1 (372–388 ms), TW2 (538–576 ms), TW3 (648–680 ms) and TW4 (743–776 ms). For these time windows, we exported mean amplitudes for data analysis.[12]

Data were analysed by downsampling to 48 electrodes and defining twelve different regions of interest (ROIs) consisting of four neighbouring electrodes each. We defined the following ROIs: left-posterior (O1, O9, P3, P7), left-posterior-medial (CP3, CP5, M1, TP7), left-anterior-medial (C3, C5, FC5, T7), left-anterior (AF3, AF7, F5, FT7), mid-posterior (Oz, PO1, PO2, Pz), mid-posterior-medial (CP1, CP2, CPz, Cz), mid-anterior-medial (F1, F2, FCz, Fz), mid-anterior (AFz, FP1, FP2, FPz), right-posterior (O10, O2, P4, P8), right-posterior-medial (CP4, CP6, M2, TP8), right-anterior-medial (C4, C6, FC6, T8), and right-anterior (AF4, AF8, F6, FT8). For data analysis, the mean amplitude across all four electrodes in a chosen time window was used as the dependent variable.

For the analyses in all reported time windows, we monitored the influence of the linguistic factors DIP, POSITION and CLAUSE TYPE, together with the influence of ROI. Analysis set out with an ANOVA of the main effects and full four-way interaction between all linguistic factors and ROI. Interactions were pursued in a hierarchical fashion, beginning with a resolution for different levels of position, and aiming for contrasts between *denn* and *jetzt*. Huyhn-Feldt corrections were performed if the degree of freedom in the numerator was higher than 1. In these cases, we report

[12] We decided to identify time windows using the data-driven approach outlined above in order to take the partly exploratory nature of our research question into account, following the suggestions of a reviewer. At the same time, wishing to provide a link between our findings and the older ERP literature on N400/P600 effects and NPI processing, we exported more traditional time windows based on visual inspection. The results for these additional time windows are given in detail in the Appendix.

original degrees of freedom, Huyhn-Feldt ε values, and corrected probability levels. Following our experimental design outlined above, we limit the report of our findings to effects that are relevant for our research question, namely, main effects and interactions of DIP.[13] For the sake of brevity and readability, we resolve only the most complex interactions of DIP with other factors. All effects reported are statistically significant, unless stated otherwise.

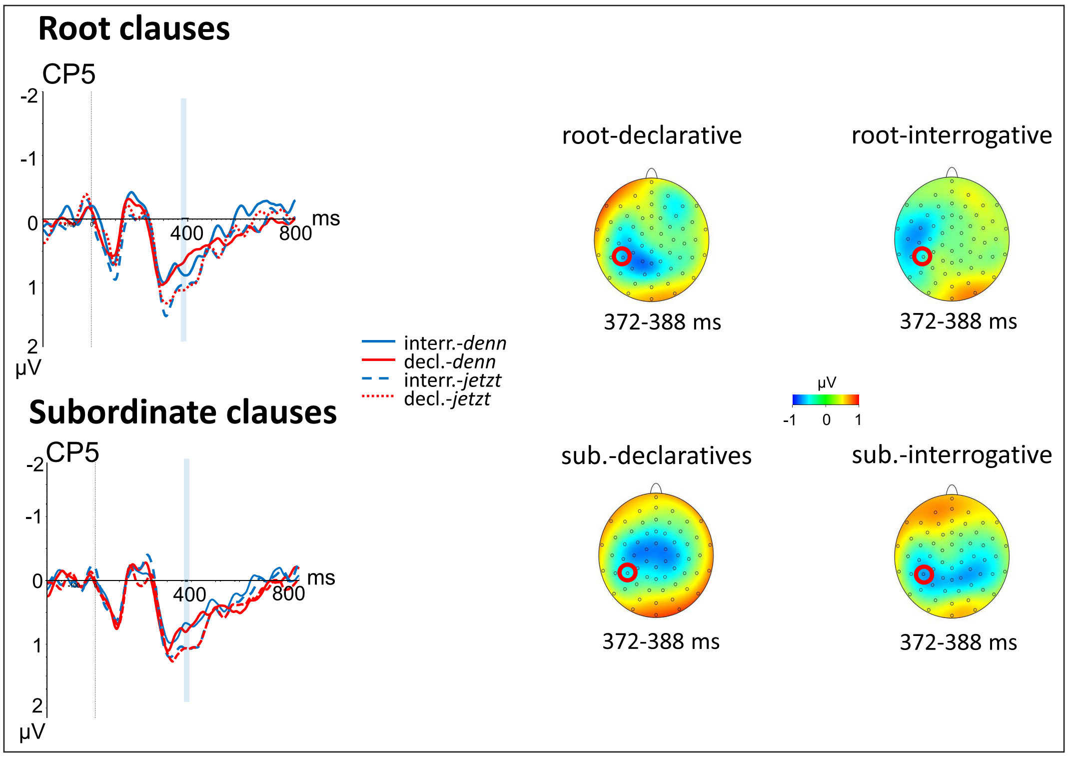

Figure 1: ERP results for time window 1 from 372–388 ms. The upper half illustrates the results for root clauses, the lower half illustrates the results for subordinate clauses. Grand average ERP waveforms for one representative EEG channel and all 4 root or subordinate clause conditions are shown at the left side. The right side of the figure shows the mean topographies in time window 1 for the difference between the corresponding *denn* and *jetzt* conditions. Red circles indicate the position of the representative EEG channel.

3.2 ERP results

Descriptively speaking, curves for *denn* were more negative-going than for *jetzt* around 400 ms at left-medial electrode sites; this became slightly more visible in subordinate clauses than in root clauses, and in declaratives than in interrogatives. There was also a clearly visible P600 effect for

[13] Remember that the presence of the conditions containing *jetzt* allows us to distinguish between simple effects of clause type and position affecting sentence processing in general, and those that are relevant for QDiP processing in particular. Please see Section 5 for an in-depth discussion of the interplay of lexical differences and complex licensing processes in different aspects of our results.

conditions with *denn*, relative to conditions with *jetzt*. The P600 seemed to be of shorter duration for interrogatives than for declaratives, especially in subordinate clauses.

We only report effects involving DIP. Interactions involving the factor DIP are resolved hierarchically. For reasons of brevity, we limit our detailed report to the highest interaction involving each factor.

Voltage difference maps and grand averages for a representative EEG channel are given in **Figure 1** for time window 1 and in **Figure 2** for time windows 2, 3 and 4.

TW1 (372–388 ms): Descriptively, curves were more negative-going for *denn* than for *jetzt* conditions. There was a main effect of DIP ($F(1,30) = 6.60$, $p < .05$.[14]

TW2 (538–576 ms): Descriptively, curves for *denn* were more positive-going than those for *jetzt* in declaratives, while amplitudes for interrogatives remained between those for different declarative conditions. This pattern became visible in central and central-right-posterior sites. There was a main effect of DIP ($F(1,30) = 7.25$, $p < .05$), and an interaction of DIP, POSITION and CLAUSETYPE ($F(1,30) = 6.90$, $p < .05$). In root clauses, there was an interaction of DIP and CLAUSETYPE ($F(1,30) = 6.05$, $p < .05$; DIP significant in declaratives, F(1,30) = 7.56, $p < .05$, but not in interrogatives, $p > .9$). In subordinate clauses, there was a main effect of DIP ($F(1,30) = 7.15$, $p < .05$).

TW3 (648–680 ms): Descriptively, curves were more positive-going for *denn* than *jetzt* at central and central-right-posterior sites. This pattern became especially visible in root clauses. There was a main effect of DIP ($F(1,30) = 5.21$, $p < .05$), an interaction of DIP and POSITION ($F(1,30) = 4.58$, $p < .05$; DIP significant in subordinate clauses, $F(1,30) = 7.95$, $p < .01$, but not in root clauses, $p > .2$), and an interaction of DIP and ROI ($F(11,330) = 4.6$, $p < .05$, HF $\varepsilon = .40$). DIP was significant in ROIs right-posterior ($F(1,30) = 5.22$, $p < .05$), right-posterior-medial ($F(1,30) = 13.75$, $p < .001$), right-anterior-medial ($F(1,30) = 6.44$, $p < .05$), mid-posterior ($F(1,30) = 10.22$, $p < .01$), mid-anterior ($F(1,30) = 8.50$, $p < .01$), left-anterior ($F(1,30) = 7.95$, $p < .01$), and marginal in mid-posterior-medial ($F(1,30) = 3.91$, $p < .06$).

TW 4 (734–776 ms): Descriptively, curves for *denn* were more positive-going than curves for *jetzt* in declaratives, but not in interrogatives. There was a significant main effect of DIP ($F(1,30) = 7.18$, $p < .05$). There were interactions of DIP, POSITION and CLAUSETYPE ($F(1,30) = 5.77$, $p < .05$), DIP and ROI ($F(11, 330) = 7.18$, $p < .01$, HF $\varepsilon = .21$), POSITION and ROI $F(11,330) = 3.35$, $p < .05$, HF $\varepsilon = .25$), and a four-way interaction of DIP, POSITION, CLAUSETYPE, and ROI ($F(11,330) = 2.98$, $p < .05$, HF $\varepsilon = .23$). The four-way interaction was resolved by pursuing the interaction of DIP, CLAUSETYPE and ROI separately for each level of POSITION.

[14] See the Appendix for an analysis of the more traditional N400 time window from 380–420 ms, reporting additional interactions of DIP with other factors.

For root clauses, there was an interaction of DIP and CLAUSETYPE (F(1,30) = 10.91, $p < .01$; CLAUSETYPE significant for *denn*, F(1,30) = 5.33, $p < .05$, but not for *jetzt*, $p > .4$).

For subordinate clauses, there was a three-way interaction of DIP, CLAUSETYPE and ROI (F(11,330) = 4.30, $p < .01$, HF ε = .29). The three-way interaction was resolved by pursuing the interaction of DIP and CLAUSETYPE separately for each ROI. The interaction of DIP and CLAUSETYPE was significant in the ROIs right-posterior (F(1,30) = 5.98, $p < .05$), right-posterior-medial (F(1,30), = 5.54, $p < .05$), right-anterior (F(1,30), = 5.54, $p < .05$), mid-posterior (F(1,30) = 4.56, $p < .05$), mid-anterior-medial (F(1,30) = 6.10, $p < .05$), mid-anterior (F(1,30) = 11.62, $p < .01$), left-anterior (F(1,30) = 6.16, $p < .05$). In these ROIs, DIPS was significant for declaratives, but not for interrogatives (values for declaratives: right-posterior F(1,30) = 18.46, $p < .001$; right-posterior-medial F(1,30) = 17.94, $p < .001$; right-anterior F(1,30) = 7.05, emphp $< .05$; mid-posterior F(1,30) = 17.93, $p < .001$ – marginal for interrogatives F(1,30) = 3.41, $p < .08$; mid-frontal-medial (F(1,30) = 10.45, $p < .01$); mid-frontal F(1,30) = 15.02, $p < .001$; left-frontal F(1,30) = 21.34, $p < .001$).

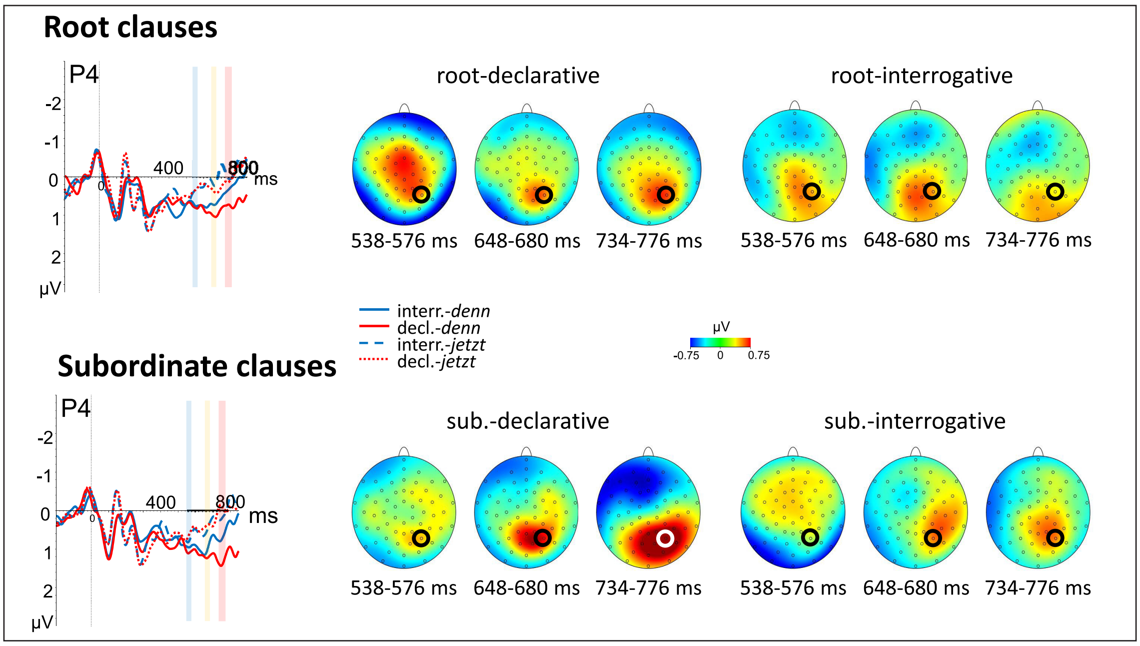

Figure 2: ERP results for time window 2 (538–576 ms), time window 3 (648–680 ms) and time window 4 (734–776 ms). The upper half illustrates results for root clauses, the lower half illustrates results for subordinate clauses. Grand average ERP waveforms for one representative EEG channel and all 4 root or subordinate clause conditions are shown at the left side. The right side of the figure shows the mean topographies in time windows 2, 3 and 4 for the difference between the corresponding *denn* and *jetzt* conditions. Black or white circles indicate the position of the representative EEG channel.

3.2.1 Summary of ERP results

All results and effects are phrased for *denn* relative to *jetzt* in the same clause type and position. TW1 showed more negative-going curves for *denn* than *jetzt* mainly at left-central-medial sites. The general pattern in TW2, TW3 and TW4 is that curves for *denn* are more positive-going than those for *jetzt* in central-right-posterior sites, with some changes between the time windows. The topography and general timing of the effect is in line with a P600 effect. For TW2, the statistical analysis suggests that the P600 is enhanced for *denn* when syntactic/semantic licensing constraints are not met, i.e., for *denn* in declaratives and in interrogative subordinate clauses. For TW3, the P600 is enhanced for *denn*, relative to *jetzt*, in subordinate clauses. For TW4, the P600 for *denn* is enhanced in declaratives, but not in interrogatives, in contrast to TW2. Our interpretation of these findings is given in Section 5.

4. Time-frequency analysis

4.1 Data preparation and analysis

Time-frequency decomposition was performed on the epochs –2000 ms to 2600 ms with help of the MATLAB-based FieldTrip toolbox, developed at the F.C. Donders Centre for Cognitive Neuroimaging in Nijmengen, Netherlands (Oostenveld et al., 2011). It was done for each channel and each trial, using a set of complex Morlet wavelets for frequencies ranging from 1 to 30 Hz in 1 Hz-step for 1–20 Hz range, and 2 Hz step for 20–30 Hz range with a frequency specific width, linearly increasing from 2 to 12 cycles. The resulting output was a complex Fourier spectrum. A baseline correction was applied 500 ms before the onset of the QDiP/non-QDiP item presentation. The reason for this baseline window was to avoid contamination by the response triggered by the sequential visual presentation of the words.

To determine the statistical significance of differences between QDiP and non-QDiP conditions in different clause types (declarative and interrogative) and positions (root and subordinate), we applied a multi-level statistical approach. First, we calculated independent samples regression coefficient t-tests for the whole epoch. The conditions were contrasted against each other in a pairwise manner. The obtained t-values were subsequently z-transformed. Then, we calculated Monte Carlo non-parametrical cluster-based permutation tests with 2000 randomizations for 900 ms after the onset of the critical words, to determine significance probabilities (cluster $\alpha < 0.05$) (Maris & Oostenveld, 2007).

4.2 Time-frequency results

Overall, less theta enhancement was observed for the QDiP *denn* than for the non-QDiP *jetzt*. We found statistically significant differences between *denn* and *jetzt* from 30–790 ms for root declarative clauses, from 310–760 ms for root interrogative clauses, and 80–430 ms for subordinate interrogative clauses. Statistically significant differences found in the time-frequency analysis are illustrated in **Figure 3**.

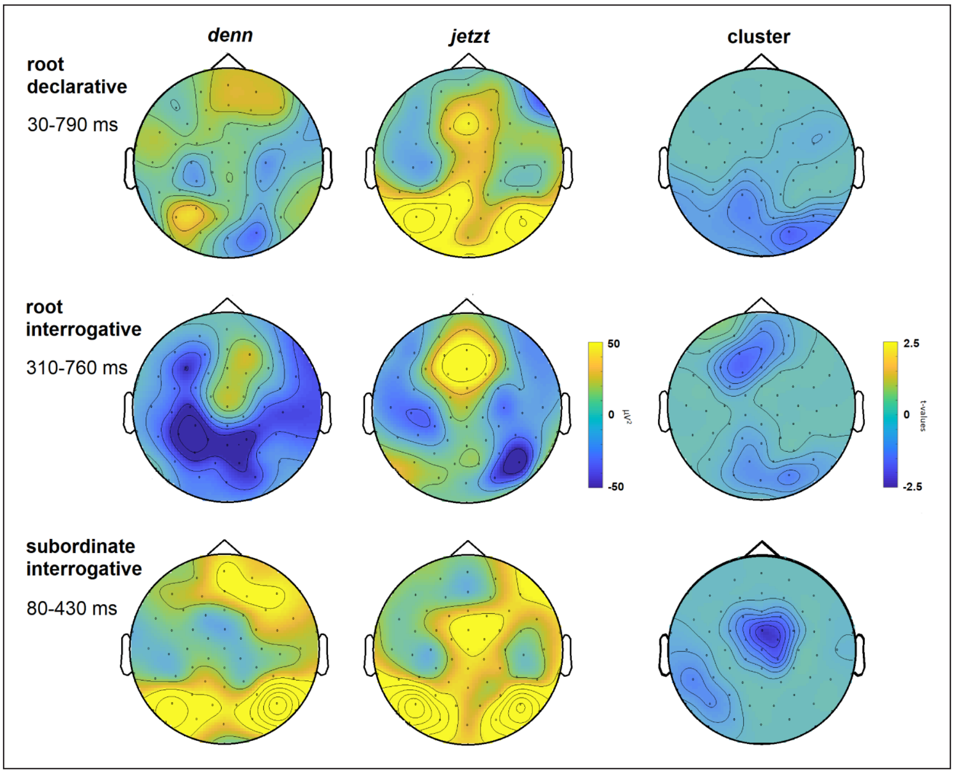

Figure 3: The significant differences in the theta band activity found for the QDiP *denn* (the first column) and the non-QDiP *jetzt* (the second column). The third column represents the distribution of clusters indicating the significant difference between the *denn* and *jetzt* conditions. The upper row depicts results for declarative root clauses, the middle row depicts results for interrogative root clauses, and the lower row depicts results for subordinate interrogative clauses. No significant differences were found in subordinate declarative clauses. Power is averaged over the latency range for which significant differences were found as a result of a Monte Carlo cluster-based permutation test.

Significant differences were observed for root declaratives and interrogatives in the posterior areas. Additionally, the cluster distribution for declaratives with *denn* and *jetzt* in root clauses included the right-lateralized fronto-central area, whereas the distribution of fronto-central clusters for interrogatives was more anterior and slightly left lateralized. The interrogatives with *denn* and *jetzt* in subordinate clauses exhibited a central and left lateralized temporal and parietal-occipital cluster topography. No significant difference between QDiP and non-QDiP was found for the declaratives with *denn* and *jetzt* in subordinate clauses.

5. General discussion and conclusion

We found the following results, repeated here for convenience (described relative to the corresponding *jetzt* baseline):

- More negative-going curves for *denn*, relative to *jetzt*, around 380 ms at left-central electrode sites (TW1).
- More positive-going curves for *denn*, relative to *jetzt*, in declarative and in interrogative-subordinate conditions (TW2) beginning after 530 ms.
- More positive-going curves for *denn*, relative to *jetzt*, only in subordinate clauses, beginning around 650 ms.
- More positive-going curves for *denn*, relative to *jetzt*, only in declaratives, beginning around 730 ms.

5.1 Interpretation of the early negativity

The first analysed time window (TW1, 372–388 ms) showed more negative-going curves for *denn* vs. *jetzt*.[15] We consider two ways to interpret this result. The first is to interpret this as a subtle N400 effect, i.e., an enhancement of the N400 for *denn*, relative to *jetzt* (in an earlier time window and at slightly more left electrode sites than would be expected for a classical N400). In the neurolinguistic literature, the N400 has been associated with the relative ease of lexical access for single words, both in isolation and in the sentence context. It thus reflects both single-word and sentence level processing (see Kutas & Federmeier 2011; Lau et al. 2008; and Baggio & Hagoort 2011, for a thorough review of the N400 in the context of the memory-unification-control model of language comprehension; see also Hagoort 2013, 2016, for further details). An increase in the N400 can reflect reduced lexical pre-activation, but also increased workload during semantic unification processes. In the NPI literature, there are many reports of enhanced N400s for unlicensed NPIs, relative to licensed NPIs (see Drenhaus et al. 2005, 2007; Liu et al. 2019; Saddy et al. 2004; Shao & Neville 1998; Xiang et al. 2013; Yanilmaz & Drury 2018; Yurchenko et al. 2013), but this is in contrast to Steinhauer et al. (2010) and Xiang et al. (2009).[16] In contrast to these NPI results, the findings for TW1 do not allow us to report a difference in N400 amplitude between licensed and unlicensed QDiPs. Given that the amplitude differences are not very striking, subtle differences between conditions may not surface as statistically significant results. (See, however, the analysis of a slightly later time window in the Appendix that is more in line with the result pattern reported for the N400 in the NPI literature).

---

[15] Please refer to the Appendix for an analysis of the time window from 380–420 ms, leading to additional interactions of DIP with the other factors.

[16] In Steinhauer et al. (2010), an attenuation of the N400 for function words (like NPIs), relative to content words, is predicted and discussed in the context of the former being 'devoid of meaning'. Differences in whether NPI licensing violations lead to an N400 enhancement seem to depend on details of stimulus construction, and to be linked to the relative level of surprise upon encountering the NPI in the licensed contexts – see Yurchenko et al. (2013) for an in-depth discussion. We will return to this issue when discussing the results of the time-frequency analysis.

The second possible interpretation is a P300 attenuation for *denn* relative to *jetzt*.[17] Based on the P300 literature overview in Polich (2007), there are different processes that influence the P300, all linked to ongoing memory update. In this framework, the most likely explanation for our current findings would be an attenuation of the P300 amplitude for *denn*, relative to *jetzt*, due to higher cognitive demands interfering with memory update (see Polich 2007, p. 2137). The only difference in cognitive demands that encompasses all *denn* conditions, in contrast to all *jetzt* conditions, would be that with *denn*, it is necessary to check if the syntactic, semantic and pragmatic licensing conditions are met.

The current contribution is the first report of this early negativity found in QDiP licensing, and the effects are statistically reliable but quite subtle. We therefore refrain from deciding between the two interpretations at this point. Both the P300 and the N400 are elicited by deviant stimuli, although the exact kind of deviance eliciting each may differ, and both are likely to interact in non-trivial ways (Alday & Kretzschmar 2019; Arbel et al. 2011; see also Roehm et al. 2007). Given the latency of the time windows in our findings, both interpretations are possible, in principle, and need not be mutually exclusive. At this point in time, both should be taken into account when formulating predictions for follow-up studies.

5.2 Interpretation of late positivities

Beginning at 538 ms and extending until the end of the segment, there were three different time windows showing more positive-going waveforms for *denn*, relative to *jetzt*, in some conditions, at central to right-posterior electrode sites. We interpret these positivities as a P600 effect. In the earliest P600 time window (TW2, 538–576 ms), the P600 effect occurs for violations of syntactic and semantic licensing constraints: In root clauses, the P600 was enhanced for *denn* in declaratives. In subordinate clauses, the P600 was enhanced for *denn* in declaratives and interrogatives (remember that *denn* in the interrogative-subordinate condition can only be licensed pragmatically, not syntactically). In the middle P600 time window (TW3, 648–680 ms), the P600 was enhanced for *denn*, with the typical P600 topography becoming more pronounced. The statistical analysis showed that this P600 effect was stronger in subordinate clauses than in root clauses. We interpret the findings for this time window as reflecting the ongoing processing load associated with *denn* licensing, both in interrogatives and in declaratives. The significant effect for subordinate clauses lines up with the idea that *denn* licensing in subordinate clauses

[17] The P300 is a positive deflection in the EEG waveform, peaking roughly around 300 ms. It is often described as a member of the wider P3 family. Described since the 1960ies (Chapman & Bragdon, 1964; Sutton et al., 1965), it has been associated with a high number of different task-related processes, and is known to be related to the processing of oddball stimuli, context updating, attention and possibly decision-making. See Leckey & Federmeier (2020) for a current review of language-related positivities including the P300, and Swaab et al. (2012) for an overview of language-related ERP components in general, including the P3 family and the N400. We are grateful to an anonymous reviewer pointing out this possible interpretation.

is associated with high processing load even for interrogatives, since it can only be achieved via pragmatic licensing (shown to be costly in Czypionka et al., 2021). In the latest P600 time window (TW4, 734–776 ms), the P600 effect reflected whether QDiP can be licensed in any way at all, including pragmatic licensing: The P600 effect became significant for *denn* in declaratives. Unlike the effects found in the early P600 time window, there was no P600 for subordinate interrogative *denn*. The only difference between root and subordinate clauses was that in subordinate clauses, the topographical effects also reached significance.

We assume that the early P600 reflects the processing of syntactic and semantic licensing constraints – the P600 is enhanced when “straightforward” syntactic-semantic *denn*-licensing is not possible, i.e., in interrogatives with *denn* in subordinate clauses (which can only be licensed pragmatically) and in all declaratives. The middle P600 time window shows a P600 enhancement for *denn*, especially in subordinate clauses – we take this to reflect the general increase in processing load associated with the processing of discourse particles, both with and without licensing violations (but more pronounced in subordinate clauses, which always contain violations of some of the licensing constraints). Finally, the latest P600 time window shows an enhanced P600 for *denn* vs. *jetzt* in declaratives, but not in interrogatives. Different from the P600 found in the early time window, this now holds for both root clauses and subordinate clauses. We take this to reflect the fact that, at this point in time, pragmatic licensing for *denn* in interrogative-subordinate clauses has taken place, making the sentences licit, while *denn* in the declarative-subordinate condition remains ill-formed.

Taken together, the early P600 reflects violations of syntactic/semantic QDiP licensing constraints, while the late P600 reflects these violations plus the possibility of “saving” the interpretation via pragmatic licensing. Between these two time frames, the middle P600 time window can be argued to reflect the general processing load associated with the (successful or unsuccessful) integration of QDiPs into the sentence context. In the case of *denn* in declaratives, this reflects the failure of syntactic, semantic and pragmatic licensing processes. In the case of *denn* in interrogatives, this may reflect the workload involved in successfully checking these licensing constraints (which is not necessary for integrating *jetzt*). Especially in the case of subordinate *denn* in interrogatives, we assume a high pragmatic contribution to this P600 increase.

The literature shows different instances of P600 in syntactically well-formed clauses with increased pragmatic processing load (see De Grauwe et al., 2010, for metaphors; Coulson & Lovett, 2010, for indirect requests; and Regel et al. 2011b; Spotorno et al. 2013, for irony). For NPI licensing, Xiang et al. (2016) report a P600 increase, relative to NPIs licensed by explicit negation, both for unlicensed NPIs and for implicitly licensed NPIs (where implicit licensing refers to licensing by emotive verbs like *surprise*), with small latency and topographical differences between both P600s. The authors interpret the P600 for implicit licensing in well-formed sentences as reflecting the additional pragmatic workload associated with implicit, relative to explicit, licensing. They interpret the differences between both P600s as reflecting the difference between failed and ultimately successful pragmatic integration.

'Implicit' NPI licensing should not be confused with the pragmatic licensing pathway proposed for QDiPs, in part because implicit NPI licensing should involve a stronger semantic contribution than pragmatic QDiP licensing. Still, findings for both phenomena suggest that costly, but ultimately successful, licensing processes can enhance the P600, leading to differences in timing and possibly topography relative to well-formed conditions involving less workload, but also to ungrammatical constructions where licensing ultimately fails.

The shorter P600 for *denn* in interrogatives as opposed to declaratives also mirrors earlier behavioural findings reported in Czypionka et al. (2021). There, *denn* in interrogative subordinate clauses was associated with an unexpectedly mild drop in acceptability ratings, and no increases in reading times relative to the baseline (unlike unlicensed *denn*, which led to reading time increases).

Our current electrophysiological findings are in line with this, suggesting that the intervening clause barrier leads to an increase in processing cost, but not to the same extent as an absent licenser.

5.3 Interpretation of time-frequency analysis

The analysis of the power changes in the theta frequency range for QDiPs and non-QDiPs in root and subordinate clauses in declaratives and interrogatives showed an enhancement for the non-QDiP *jetzt*, relative to the QDiP *denn*. In previous studies, an increase in the theta power was reported as a reflection of semantic, but not syntactic, violations (Hald et al., 2006; Li et al., 2017; Pu et al., 2020). In line with these earlier findings, our data also show that the theta band activity does not seem to depend on the well-formedness of the clause. The attempt to integrate the QDiP *denn* with an absent or inaccessible licenser does not result in a power increase compared to the baseline non-QDiP *jetzt* condition. The theta power is more enhanced for *jetzt* relative to *denn*. This holds for declaratives (absent licenser) and interrogatives (accessible licenser) in root clauses as well as for interrogatives (inaccessible licenser) in subordinate clauses.

In the literature, theta activity has been reported to be sensitive to the contrast between open and closed class words (Bastiaansen & Hagoort, 2006; Bastiaansen et al., 2005, 2008). This is in line with our findings, as QDiPs form a closed class, whereas adverbs (like our baseline *jetzt*) form an open class.

The distribution of the clusters showing the significant difference in theta activity between *jetzt* and *denn* is partially in accordance with this literature (Bastiaansen et al., 2005; Hald et al., 2006): a fronto-central component, a left temporal component and occipital component. The fronto-central component in our data did not show significant differences for declaratives with the QDiP/non-QDiP in root clauses, but differed significantly for both interrogative clause types. The left temporal component was found only for interrogatives with *denn* and *jetzt* in subordinate clauses. The occipital component exhibited a broader distribution compared to the literature. The fronto-central component reported by Bastiaansen et al. (2005), assumed to be associated with working memory load, did not differ in magnitude for open and closed class words. This matches our findings for declaratives (both root and subordinate), whereas we found differences between *denn* and *jetzt* for interrogatives (where QDiPs are successfully licensed). This discrepancy might depend on the type of stimulation used by Bastiaansen and coauthors (151 sentences from a Dutch fairy-tale) and the broad variety of open class and closed class words included in their analysis.

The left temporal component has been associated with lexical meaning retrieval. We observed it for interrogative subordinate clauses. This might be a subtle reflection of lexical meaning retrieval happening for *jetzt*, whereas *denn* does not have a concrete lexical meaning beyond its non-at-issue contribution to sentence meaning. The occipital area difference might reflect visual word processing: the non-QDiP *jetzt* is not only longer than *denn* but is also graphically more complex.

The results for the contrast between *denn* and *jetzt* in declarative-subordinate conditions do not fit easily into the pattern observed in the other three contrasts. In the ERP analysis, this contrast is associated with a robust and long-lasting P600. However, the time-frequency analysis did not reveal any significant difference between these conditions. We might speculate that the potential effects of lexical and working memory differences in the oscillatory signal are too subtle to be picked up by our statistical analysis.

In sum, in our data, theta oscillations seem to reflect general lexical differences between *denn* and *jetzt*, like the "semantic weakness" of the former, relative to the latter. This becomes more clearly visible in interrogatives (i.e., with successful QDiP licensing). Future studies should address the contrast between particles and non-particles using stimuli without grammatical violations, in order to reach a clearer pattern of results.

5.4 Complementary insights from ERP and time-frequency analyses

As known from literature, both the N400 and theta power increase reflect semantic information integration (see, e.g., Davidson & Indefrey 2007, for a comprehensive review of studies examining changes in both the N400 and the theta band; see also Schneider & Maguire 2018, **Table 1**).[18] One might expect the increase in theta power as well as in the N400 amplitude to

[18] If we interpret the finding in TW1 as an increase in P300 for *jetzt* relative to *denn*, this would correspond to the increase in theta power for *jetzt* relative to *denn*. Klimesch et al. (2000) report P300 amplitude and theta power increases for access to memorized words related to the old/new effect. While the general direction of our findings lines up with the findings in Klimesch et al. (2000), the studies differ substantially in stimulus material and methodology, and thus do not allow a transfer of interpretations.

reflect the enhanced semantic processing load. However, we did find a negativity that can be interpreted as an increase in N400 amplitude. This suggests that we are tapping into different aspects of lexico-semantic processing with these two different analyses. As outlined above, we assume that the N400 increase for *denn*, relative to *jetzt*, reflects enhanced processing costs for semantic integration, and, in the case of unlicensed *denn* in declaratives, possibly lower predictability for QDiPs in non-interrogative contexts. In contrast, the decreased theta power for *denn*, relative to *jetzt*, is most easily explained as reflecting different word classes/*denn*'s lack of at-issue content.[19]

5.5 Conclusion

In our study, we investigated QDiP licensing as a complex phenomenon at the interfaces of syntax, semantics and pragmatics. QDiP processing, in general, was reflected in an early negativity (interpretable at this point as an N400 increase or P300 attenuation), and an increase in P600 amplitude. For structures with successful QDiP licensing, we observed a P600 increase, relative to the non-QDiP baseline, albeit a shorter one than the one found for QDiP licensing violations. For conditions triggering pragmatic QDiP licensing (*denn* in subordinate clauses), the early P600 time windows patterned with those for outright licensing violations (*denn* in declaratives), while the late P600 time window patterned with those for syntactically well-formed conditions. The lack of at-issue content for the QDiPs is reflected in lower theta power, relative to the baseline. Taken together, our findings reflect a complex interplay of syntactic, semantic and pragmatic factors.[20]

The two types of EEG data analyses we employed complement each other and tap into different aspects of discourse particle processing. Together, they allow us to work towards a closer connection of theoretical and neurolinguistic approaches and a more complete picture of language comprehension

[19] In general, closed-class words are associated with reduced N400s, relative to open-class words (Kutas & Hillyard 1983; Münte et al. 2001; Nobre & McCarthy 1994; see van Petten & Kutas, 1991, for a reduced and left-shifted N400 for closed class, relative to open class, words). At first, this seems to run counter to our finding an increased N400 for QDiPs, relative to the baseline. We speculate that the N400 was increased due to the semantic unification processes outlined above, but that this increase was, in turn, attenuated, due to the closed-class nature of *denn*.

[20] An anonymous reviewer suggested that we offer an analysis of differences in individual participants' result patterns and QDiP licensing strategies. While we agree that this is a very promising direction for future research, an investigation of individual participants' result patterns and strategies in QDiP licensing is beyond the scope of the current article. We chose a relatively high number of participants (for a current neurolinguistic study of sentence processing) to enable us to identify the relevant components related to QDiP processing; this lays important groundwork for future studies. A follow-up study on interindividual variation in QDiP licensing with clearly formulated hypotheses would need to be based on (a) our current study, to allow for clear ERP predictions, and (b) a thorough behavioral assessment of interindividual differences in QDiP licensing, to allow an interpretation of ERP findings. Once these are in place, a new ERP study with a much higher number of participants may be informative.

Appendix

The time windows analyzed in the main body of this paper were identified using a data-driven approach. While this approach takes into account the exploratory nature of our research question, we are also keen to provide a link to the older existing literature on NPI licensing, as well as to the earlier report of our current ERP data using a different parametrization of the topographical information. In addition, data-driven time window identification may be problematic for complex experiment designs and subtle effects of interest, so supplementing our analysis with another approach to time window identification seems advisable. For this reason, we provide this Appendix presenting the results for three additional time windows that we identified based on our expectations of finding N400 and P600 effects, as well as on visual inspection. We will discuss the subtle differences between the outcomes of both analyses along with the general parallels.

ERP results, time windows based on visual inspection

Early negativity: 380–420 ms

Voltage difference maps and grand averages for a representative EEG channel illustrating this time window are found in **Figure A1**.

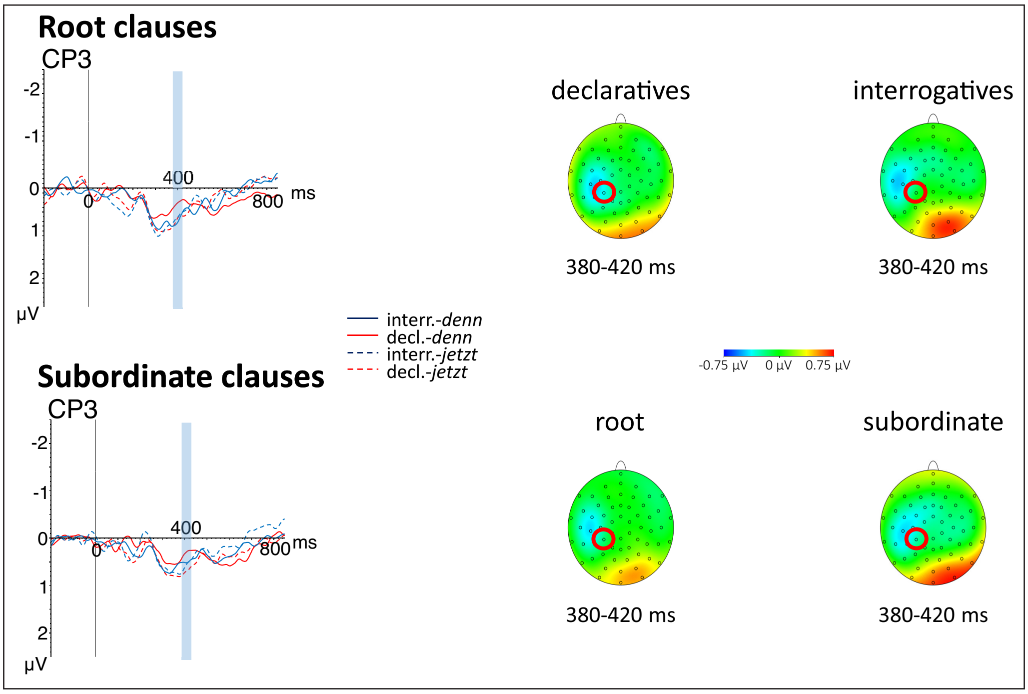

Figure A1: ERP results for 380-420 ms time window. Curves in the upper half illustrate the negativity found in root clauses, curves in the lower half illustrate the negativity found in subordinate clauses. Grand average ERP waveforms for one representative EEG channel and all 4 experimental conditions are shown at the left side. The right side of the figure shows the mean topographies in this time window time windows for the difference between the corresponding *denn* and *jetzt* conditions, collapsed across positions in the upper half, and collapsed across clause types in the lower half. Red or black circles indicate the position of the representative EEG channel.

There was an interaction of DIP and POSITION ($F(1,30) = 5.65$, $p < .05$) and an interaction of DIP and CLAUSETYPE ($F(1,30) = 4.49$, $p < .01$) The main effect of DIP was significant in subordinate clauses ($F(1,30) = 9.39$, $p < .05$), but not in root clauses ($p > .8$). The main effect of DIP was significant for declaratives ($F(1,30) = 6.99$, $p < .05$), but not for interrogatives ($p > .7$).[21]

Early P600 time window: 600-700 ms

Voltage difference maps and grand averages for a representative EEG channel illustrating the early and late P600 are found in **Figure A2**. There was a main effect of DIP ($F(1,30) = 4.50$, $p < .05$); and interactions of ROI with DIP ($F(11,330) = 5.13$, $\varepsilon = .22$, $p < .01$), POSITION ($F(11,330) = 11.52$, $\varepsilon = .41$, $p < .001$) and CLAUSETYPE ($F(11,330) = 3.52$, $\varepsilon = .28$, $p < .05$). There were no interactions of DIP with POSITION or CLAUSETYPE. The main effect of DIP was significant in ROIs right-anterior-medial ($F(1,30) = 9.93$, $p < .01$), right-posterior-medial ($F(1,30) = 15.66$, $p < .001$), right-posterior ($F(1,30) = 6.91$, $p < .05$), mid-anterior $F(1,30) = 7.59$, $p < .01$), mid-posterior ($F(1,30) = 7.99$, $p < .01$), left-anterior ($F(1,30) = 10.03$, $p < .01$), and left-posterior-medial ($F(1,30) = 4.88$, $p < .05$).

Late P600 time window: 700-800 ms

There was a statistically significant three-way interaction of DIP, POSITION and CLAUSETYPE ($F(1,30) = 4.96$, $p < .05$, and a four-way interaction of DIP, POSITION, CLAUSETYPE and ROI that was marginally significant ($F(11,30) = 2.82$, $\varepsilon = .24$, $p = .0503$).

The three-way interaction was resolved by pursueing the interaction of DIP and CLAUSETYPE separately for both levels of POSITION. In root clauses, there was an interaction of CLAUSETYPE and DIP ($F(1,30) = 10.59$, $p < .01$). The simple effect of DIP was significant for root-declaratives ($F(1,30) = 5.69$, $p < .05$), but not for root-interrogatives ($p > .2$). In subordinate clauses, there was a main effect of DIP ($F(1,30) = 8.79$, $p < .01$).

The four-way interaction was resolved by pursueing the interaction of DIP, CLAUSETYPE and ROI separately for both levels of POSITION. For root clauses, there were interactions of of DIP and ROI ($F(11,330) = 3.65$, $p < .05$, $\varepsilon = .25$), and of CLAUSETYPE and DIP ($F(1,30) = 10,59$; $p < .01$; resolution is identical to the one described for the three-way interaction). For subordinate clauses, there was a main effect of DIP ($F(1,30) = 8.79$, $p < .01$), an interaction of DIP and ROI ($F(11,330) = 8.76$, $p < .001$, $\varepsilon = .27$), and an interaction of DIP, CLAUSETYPE and ROI ($F(11,330) = 2.98$, $p < .05$, $\varepsilon = .30$). The interaction of DIP and CLAUSETYPE was significant in the ROIs left-anterior ($F(1, 30) = 4.85$, $p < .05$), mid-anterior ($F(1,30) = 6.85$,

[21] In the earlier analysis of the experiment published in Czypionka et al. (2022), we did not report a negativity during this time window. This is most likely due to the changes we made to the data analysis; the older analysis included fewer electrodes and missed the enhancement at the medial-left sites reported here.

$p < .05$), right-posterior-medial ($F(1,30) = 8.76$, $p < .01$), and right-posterior ($F(1,30) = 4.72$, $p < .05$). In these ROIs, the simple effect of DIP was significant for declaratives, but not for interrogatives (values for declaratives: left-anterior $F(1,30) = 17.37$, $p = .001$; mid-anterior $F(1,30) = 11.46$, $p < .01$; right-posterior-medial $F(1,30) = 25.65$, p .001; right-posterior $F(1,30) = 18.10$, $p < .001$).

Summary ERP results for time windows based on visual inspection

From 380-420 ms, there is a small negativity enhancement for *denn* relative to *jetzt*. This is visible more clearly in declaratives than interrogatives, and in subordinate than in root clauses. While there is no statistically significant three-way interaction, the enhancement is descriptively most striking for declaratives with *denn* in the subordinate clause. – This early time window differs most between both analyses. The data-driven approach identified only the earlier part of this time window from 372 to 388 ms (TW1), leaving out the later half where the effect became descriptively more visible at the left-central electrode sites. This may be due to the subtlety of the effect and to the fact that the effect was restricted to a few electrode sites. The main difference

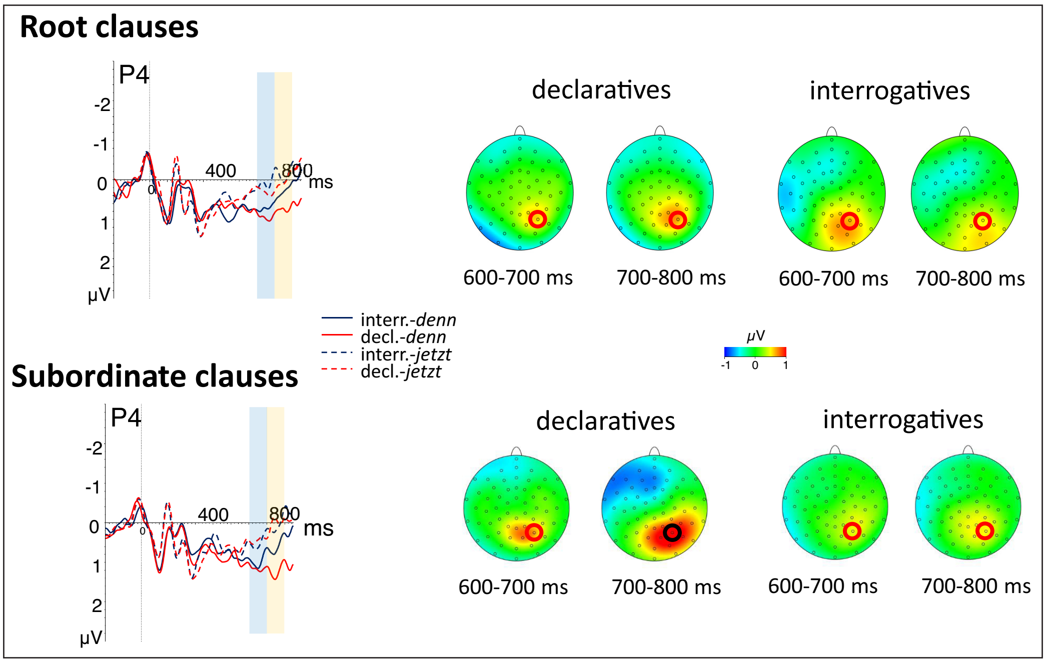

Figure A2: ERP results for the P600 time window. The upper half illustrates the P600 found in root clauses, the lower half illustrates the P600 found in subordinate clauses. Grand average ERP waveforms for one representative EEG channel and all 4 experimental conditions are shown at the left side. The right side of the figure shows the mean topographies in the early and late P600 time windows for the difference between the corresponding *denn* and *jetzt* conditions. Red or black circles indicate the position of the representative EEG channel.

for the results is that the data-driven approach picks up a general difference between *denn* and *jetzt*, while the visually defined time window additionally resolves some of the descriptively visible more subtle distinctions between the conditions, suggesting that the waveforms in this time window are sensitive also to licensing violations. The above discussion about whether to interpret this negativity as an enhanced N400 or an attenuated P300 holds for the results of the visually defined time windows, too. It might be argued that the findings for the visually defined time windows are somewhat more in line with the general direction of results for NPI licensing reporting an N400 increase for unlicensed NPIs (see the discussion of TW1 above for references). – Despite these subtle differences in resolution, both analyses find enhanced negativities for *denn* around this time.

In the early P600 time window, the most prominent effect is an enhanced P600 for *denn* relative to *jetzt*, independently of clause type and position.[22] There was no interaction of DIP with either of the other experimental factors. Compared to the data-driven approach, this time window begins between TW2 and TW3, and ends 30 ms after the end of TW3. The results line up roughly with those found in TW3, with the main finding being a P600 enhancement for *denn* relative to *jetzt* (especially in subordinate clauses; no three- or four-way interactions to allow for a more subtle resolution). In the late P600 time window, the P600 for *denn* persisted in declaratives, but became attenuated for interrogatives. In subordinate clauses, this effect occurred mainly in right-posterior sites traditionally associated with the P600. In root clauses, the same tendency was descriptively visible, but the results of the statistical analysis only warranted a resolution of the DIP:CLAUSE TYPE interaction across all ROIs. The main difference between root and subordinate clauses is that the P600 for *denn* in declaratives, but not interrogatives, has higher amplitudes and is topographically more circumscribed in subordinate than in root clauses (rather than striking qualitative differences between both positions). The results of this time window roughly line up with those of TW4 from the data-driven approach, including the fact that the topography became more clearly visible or the subordinate than the root clauses.

Taken together, there are only subtle differences in the outcomes of both methods for identifying time windows. The main differences are visible in the second half of the N400/P300 time window, and the fact that the data-driven approach identifies an additional early time window where P600 amplitudes reflect syntactic well-formedness (TW2). Both analyses show an increased P600 for *denn* vs. *jetzt* that eventually wears off in all cases but the ones containing irredeemable violations, i.e., in declaratives.

[22] While there are main effects of the other linguistic factors, there was no interaction with DiP, with similar patterns found for *denn* vs. *jetzt* across clause types and positions.

Abbreviations

DiP = Discourse particle, EEG = Electroencephalogramm, ERP = Event-related potential, nonQDiP = Something that is not a question-sensitive discourse particle, NPI = Negative polarity item, QDiP = Question-sensitive discourse particle, TW = Time window.

Data accessibility statement

Data for the analyses reported in this article are available on the data repository of the University of Konstanz (KONDATA) under doi 10.48606/923bx6zxhkxthp5p.

Ethics and consent

All participants gave written and informed consent. The experiment was performed in accordance with the rules laid down in the Declaration of Helsinki, the rules of Konstanz University for ethical experimentation and data storage, and relevant national laws. Permission was granted by the ethics committee of the University of Konstanz per the IRB statement 05/2021.

Acknowledgments

We gratefully acknowledge the technical support of Oleksiy Bobrov. We are grateful to Charlotte Englert, Marc Meisezahl, Méline Bonaud, Amelie Flüg, Anna-Maria Waibel, and Gloria Esposito for student assistant support. We thank the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for funding within the project BA 1178/10.2 *The role of German particles in questions* of the FOR2111 'Questions at the Interfaces'. This project was further supported by EU 39/8-2.

Competing interests

The authors have no competing interests to declare.

Author contributions

All three authors jointly discussed and interpreted the experimental findings and wrote the article. MK and AC share first authorship. Additionally, MK was responsible for oversight of the EEG experiment, and contributed the TF analyses and expertise. AC contributed to funding acquisition, and was responsible for experiment conceptualisation, stimulus design, and ERP analysis. CE contributed to funding acquisition and experiment conceptualisation.

ORCID IDs

Mariya Kharaman: 0009-0005-5351-0324

Anna Czypionka: 0000-0003-2247-0110

Carsten Eulitz: 0000-0002-6589-5920

References

Alday, P. M., & Kretzschmar, F. (2019). Speed-accuracy tradeoffs in brain and behavior: Testing the independence of P300 and N400 related processes in behavioral responses to sentence categorization. *Frontiers in Human Neuroscience*, *13*, 285. https://doi.org/10.3389/fnhum.2019.00285

Arbel, Y., Spencer, K. M., & Donchin, E. (2011). The N400 and the P300 are not all that independent. *Psychophysiology*, *48*(6), 861–875. https://doi.org/10.1111/j.1469-8986.2010.01151.x

Baggio, G., & Hagoort, P. (2011). The balance between memory and unification in semantics: A dynamic account of the n400. *Language and Cognitive Processes*, *26*(9), 1338–1367. https://doi.org/10.1080/01690965.2010.542671

Bastiaansen, M. C., & Hagoort, P. (2006). Oscillatory neuronal dynamics during language comprehension. *Progress in Brain Research*, *159*, 179–196. https://doi.org/10.1016/S0079-6123(06)59012-0

Bastiaansen, M. C., Oostenveld, R., Jensen, O., & Hagoort, P. (2008). I see what you mean: Theta power increases are involved in the retrieval of lexical semantic information. *Brain and Language*, *106*(1), 15–28. https://doi.org/10.1016/j.bandl.2007.10.006

Bastiaansen, M. C., van Berkum, J. J., & Hagoort, P. (2002). Syntactic processing modulates the θ rhythm of the human EEG. *Neuroimage*, *17*(3), 1479–1492. https://doi.org/10.1006/nimg.2002.1275

Bastiaansen, M. C., van der Linden, M., Ter Keurs, M., Dijkstra, T., & Hagoort, P. (2005). Theta responses are involved in lexical-semantic retrieval during language processing. *Journal of Cognitive Neuroscience*, *17*(3), 530–541. https://doi.org/10.1162/0898929053279469

Bayer, J. (1991). German particles in a modular grammar: Neurolinguistic evidence. In W. Abraham (Ed.), *Discourse particles: Descriptive and theoretical investigations on the logical, syntactic and pragmatic properties of discourse particles in German* (pp. 253–302). John Benjamins. https://doi.org/10.1075/pbns.12.09bay

Bayer, J. (2012). From modal particle to interrogative marker: A study of German *denn*. In L. Brugè (Ed.), *Functional heads (the cartography of syntactic structures)* (pp. 13–28, Vol. 7). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199746736.003.0001

Bayer, J., Häussler, J., & Bader, M. (2016). A new diagnostic for cyclic *wh*-movement: Discourse particles in German questions. *Linguistic Inquiry*, *47*(4), 591–629. https://doi.org/10.1162/LING_a_00224

Bayer, J., & Obenauer, H.-G. (2011). Discourse particles, clause structure, and question types. *The Linguistic Review*, *28*(4), 449–491. https://doi.org/10.1515/tlir.2011.013

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

Chapman, R. M., & Bragdon, H. R. (1964). Evoked responses to numerical and non-numerical visual stimuli while problem solving. *Nature*, *203*(4950), 1155–1157. https://doi.org/10.1038/2031155a0

Chierchia, G. (2006). Broaden your views: Implicatures of domain widening and the "logicality" of language. *Linguistic Inquiry*, *37*(4), 535–590. https://doi.org/10.1162/ling.2006.37.4.535

Coulson, S., & Lovett, C. (2010). Comprehension of non-conventional indirect requests: An event-related brain potential study. *Italian Journal of Linguistics*, *22*(1), 107–124.

Csipak, E., & Zobel, S. (2016). Discourse particle *denn* in the antecedent of conditionals. In C. Piñón (Ed.), *Empirical issues in syntax and semantics 11* (pp. 31–60). CSSP.

Czypionka, A., Kharaman, M., Bayer, J., Romero, M., & Eulitz, C. (2022). Licensing question-sensitive discourse particles: Evidence from grammaticality judgments, self-paced reading and EEG studies. In R. Hörnig, S. von Wietersheim, A. Konietzko, & S. Featherston (Eds.), *Proceedings of Linguistic Evidence 2020: Linguistic theory enriched by experimental data* (pp. 197–215). University of Tübingen. https://publikationen.uni-tuebingen.de/xmlui/handle/10900/119301

Czypionka, A., Romero, M., & Bayer, J. (2021). Question-sensitive discourse particles at the interfaces of syntax, semantics and pragmatics – An experimental approach. *Glossa: A Journal of General Linguistics*, *6*(1), 1–24. https://doi.org/10.5334/gjgl.1203

Davidson, D. J., & Indefrey, P. (2007). An inverse relation between event-related and time–frequency violation responses in sentence processing. *Brain Research*, *1158*, 81–92. https://doi.org/10.1016/j.brainres.2007.04.082

De Grauwe, S., Swain, A., Holcomb, P. J., Ditman, T., & Kuperberg, G. R. (2010). Electrophysiological insights into the processing of nominal metaphors. *Neuropsychologia*, *48*(7), 1965–1984. https://doi.org/10.1016/j.neuropsychologia.2010.03.017

Dörre, L. (2018). *Primary and secondary meaning in the processing of German particles* [Dissertation]. University of Konstanz.

Dörre, L., Czypionka, A., Trotzke, A., & Bayer, J. (2018). The processing of German modal particles and their counterparts. *Linguistische Berichte*, *255*, 58–91. https://doi.org/10.46771/2366077500255_2

Drenhaus, H., Błaszczak, J., & Schütte, J. (2007). Some psycholinguistic comments on NPI licensing. In E. Puig-Waldmüller (Ed.), *Proceedings of Sinn und Bedeutung* (pp. 180–193, Vol. 11).

Drenhaus, H., Saddy, D., & Frisch, S. (2005). Processing negative polarity items: When negation comes through the backdoor. *Linguistic Evidence: Empirical, Theoretical, and Computational Perspectives*, 145–165. https://doi.org/10.1515/9783110197549.145

Eulitz, C., & Obleser, J. (2007). Perception of acoustically complex phonological features in vowels is reflected in the induced brain-magnetic activity. *Behavioral and Brain Functions*, *3*(1), 26. https://doi.org/10.1186/1744-9081-3-26

Felser, C., Clahsen, H., & Münte, T. F. (2003). Storage and integration in the processing of filler-gap dependencies: An ERP study of topicalization and wh-movement in German. *Brain and Language*, *87*(3), 345–354. https://doi.org/10.1016/S0093-934X(03)00135-4

Fiebach, C. J., Schlesewsky, M., & Friederici, A. D. (2001). Syntactic working memory and the establishment of filler-gap dependencies: Insights from ERPs and fMRI. *Journal of Psycholinguistic Research*, *30*(3), 321–338. https://doi.org/10.1023/A:1010447102554

Fiebach, C. J., Schlesewsky, M., & Friederici, A. D. (2002). Separating syntactic memory costs and syntactic integration costs during parsing: The processing of German WH-questions. *Journal of Memory and Language*, *47*(2), 250–272. https://doi.org/10.1016/S0749-596X(02)00004-9

Ghitza, O. (2011). Linking speech perception and neurophysiology: Speech decoding guided by cascaded oscillators locked to the input rhythm. *Frontiers in Psychology*, *2*, 130. https://doi.org/10.3389/fpsyg.2011.00130

Giannakidou, A. (2006). Only, emotive factive verbs, and the dual nature of polarity dependency. *Language*, 575–603. https://doi.org/10.1353/lan.2006.0136

Giannakidou, A. (2011). Negative and positive polarity items: Licensing, compositionality and variation. In K. von Heusinger, C. Maienborn, & P. Portner (Eds.), *Semantics: An international handbook of natural language meaning* (pp. 1660–1712, Vol. 1). Mouton de Gruyter Berlin.

Giraud, A.-L., & Poeppel, D. (2012). Cortical oscillations and speech processing: Emerging computational principles and operations. *Nature Neuroscience*, *15*(4), 511. https://doi.org/10.1038/nn.3063

Gouvea, A. C., Phillips, C., Kazanina, N., & Poeppel, D. (2010). The linguistic processes underlying the P600. *Language and Cognitive Processes*, *25*(2), 149–188. https://doi.org/10.1080/01690960902965951

Gross, J., Hoogenboom, N., Thut, G., Schyns, P., Panzeri, S., Belin, P., & Garrod, S. (2013). Speech rhythms and multiplexed oscillatory sensory coding in the human brain. *PLoS Biology*, *11*(12), e1001752. https://doi.org/10.1371/journal.pbio.1001752

Grosz, P. (2005). *"Dn" in Viennese German. The syntax of a clitic version of the discourse particle "denn"* [Diplomarbeit]. University of Vienna.

Gutzmann, D. (2009). Hybrid semantics for modal particles. *Sprache und Datenverarbeitung*, *33*, 45–49.

Gutzmann, D. (2013). Expressives and beyond: An introduction to varieties of use-conditional meaning. In *Beyond expressives: Explorations in use-conditional meaning* (pp. 1–58). Brill. https://doi.org/10.1163/9789004183988_002

Gutzmann, D. (2015). Continuation-based semantics for modal particles. Deriving syntax from semantics. *MIT Working Papers in Linguistics*, *75*, 133–150.

Haenschel, C., Baldeweg, T., Croft, R. J., Whittington, M., & Gruzelier, J. (2000). Gamma and beta frequency oscillations in response to novel auditory stimuli: A comparison of human electroencephalogram (EEG) data with in vitro models. *Proceedings of the National Academy of Sciences*, *97*(13), 7645–7650. https://doi.org/10.1073/pnas.120162397

Hagoort, P. (2013). MUC (memory, unification, control) and beyond. *Frontiers in Psychology*, *4*, 416. https://doi.org/10.3389/fpsyg.2013.00416

Hagoort, P. (2016). MUC (Memory, Unification, Control): A model on the neurobiology of language beyond single word processing. In G. Hickok & S. L. Small (Eds.), *Neurobiology of Language* (pp. 339–347). Academic Press. https://doi.org/10.1016/B978-0-12-407794-2.00028-6

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

Hagoort, P., Brown, C. M., & Osterhout, L. (1999). The neurocognition of syntactic processing. *The Neurocognition of Language*, 273–316. https://doi.org/10.1093/acprof:oso/9780198507932.003.0009

Hald, L. A., Bastiaansen, M. C., & Hagoort, P. (2006). EEG theta and gamma responses to semantic violations in online sentence processing. *Brain and Language*, *96*(1), 90–105. https://doi.org/10.1016/j.bandl.2005.06.007

Hasting, A. S., & Kotz, S. A. (2008). Speeding up syntax: On the relative timing and automaticity of local phrase structure and morphosyntactic processing as reflected in event-related brain potentials. *Journal of Cognitive Neuroscience*, *20*(7), 1207–1219. https://doi.org/10.1162/jocn.2008.20083

Hoeksema, J. (2012). On the natural history of negative polarity items. *Linguistic Analysis*, *38*(1), 3.

Iaia, C., Gili Fivela, B., Sigona, F., & Grimaldi, M. (2021). The rhythms of language: An overview of linguistic processes and neural oscillations. *JDREAM. Journal of Interdisciplinary Research Applied to Medicine*, *5*(1), 37–48.

Kaan, E., Harris, A., Gibson, E., & Holcomb, P. (2000). The P600 as an index of syntactic integration difficulty. *Language and Cognitive Processes*, *15*(2), 159–201. https://doi.org/10.1080/016909600386084

Klimesch, W., Doppelmayr, M., Schwaiger, J., Winkler, T., & Gruber, W. (2000). Theta oscillations and the ERP old/new effect: Independent phenomena? *Clinical Neurophysiology*, *111*(5), 781–793. https://doi.org/10.1016/S1388-2457(00)00254-6

König, E. (1977). Modalpartikeln in Fragesätzen. In H. Weydt (Ed.), *Aspekte der Modalpartikeln* (pp. 115–130). Niemeyer.

Kratzer, A. (1999). Beyond *ouch* and *oops*: How descriptive and expressive meaning interact. *Cornell Conference on Theories of Context Dependency*, *26*.

Kratzer, A. (2004). Interpreting focus: Presupposed or expressive meanings? A comment on Geurts and van der Sandt. *Theoretical Linguistics*, *30*(1), 123–136. https://doi.org/10.1515/thli.2004.002

Krifka, M. (1995). The semantics and pragmatics of polarity items in assertion. *Linguistic Analysis*, *15*, 209–257.

Kuperberg, G. R., Sitnikova, T., Caplan, D., & Holcomb, P. J. (2003). Electrophysiological distinctions in processing conceptual relationships within simple sentences. *Cognitive Brain Research*, *17*(1), 117–129. https://doi.org/10.1016/S0926-6410(03)00086-7

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. https://doi.org/10.1126/science.7350657

Kutas, M., & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory & Cognition*, *11*(5), 539–550. https://doi.org/10.3758/BF03196991

Ladusaw, W. A. (1996). Negation and polarity items. In S. Lappin (Ed.), *The handbook of contemporary semantic theory* (pp. 321–341). Blackwell. https://doi.org/10.1111/b.9780631207498.1997.00015.x

Laka, I. (1994). *On the syntax of negation*. Garland Publishing Co.

Lau, E. F., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics: (De)constructing the N400. *Nature Reviews Neuroscience*, *9*(12), 920–933. https://doi.org/10.1038/nrn2532

Leckey, M., & Federmeier, K. D. (2020). The P3b and P600 (s): Positive contributions to language comprehension. *Psychophysiology*, *57*(7), e13351. https://doi.org/10.1111/psyp.13351

Ledoux, K., Traxler, M. J., & Swaab, T. Y. (2007). Syntactic priming in comprehension: Evidence from event-related potentials. *Psychological Science*, *18*(2), 135–143. https://doi.org/10.1111/j.1467-9280.2007.01863.x

Li, X., Zhang, Y., Xia, J., & Swaab, T. Y. (2017). Internal mechanisms underlying anticipatory language processing: Evidence from event-related-potentials and neural oscillations. *Neuropsychologia*, *102*, 70–81. https://doi.org/10.1016/j.neuropsychologia.2017.05.017

Liu, M., König, P., & Mueller, J. L. (2019). Novel ERP evidence for processing differences between negative and positive polarity items in German. *Frontiers in Psychology*, *10*, 376. https://doi.org/10.3389/fpsyg.2019.00376

Maguire, M. J., Schneider, J. M., Melamed, T. C., Ralph, Y. K., Poudel, S., Raval, V. M., Mikhail, D., & Abel, A. D. (2021). Temporal and topographical changes in theta power between middle childhood and adolescence during sentence comprehension. *Developmental Cognitive Neuroscience*, 101056. https://doi.org/10.1016/j.dcn.2021.101056

Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG-and MEG-data. *Journal of Neuroscience Methods*, *164*(1), 177–190. https://doi.org/10.1016/j.jneumeth.2007.03.024

McCready, E. (2012). Formal approaches to particle meaning. *Language and Linguistics Compass*, *6*(12), 777–795. https://doi.org/10.1002/lnc3.360

Momsen, J. P., & Abel, A. D. (2021). Neural oscillations reflect meaning identification for novel words in context. *Neurobiology of Language*, *2*(3), 372–388. https://doi.org/10.1162/nol_a_00052

Münte, T. F., Wieringa, B. M., Weyerts, H., Szentkuti, A., Matzke, M., & Johannes, S. (2001). Differences in brain potentials to open and closed class words: Class and frequency effects. *Neuropsychologia*, *39*(1), 91–102. https://doi.org/10.1016/S0028-3932(00)00095-6

Nobre, A. C., & McCarthy, G. (1994). Language-related ERPs: Scalp distributions and modulation by word type and semantic priming. *Journal of Cognitive Neuroscience*, *6*(3), 233–255. https://doi.org/10.1162/jocn.1994.6.3.233

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

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J.-M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, *2011*, ID 156869. https://doi.org/10.1155/2011/156869

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. (1993). Event-related potentials and syntactic anomaly: Evidence of anomaly detection during the perception of continuous speech. *Language and Cognitive Processes*, *8*(4), 413–437. https://doi.org/10.1080/01690969308407584

Parker, D., & Phillips, C. (2016). Negative polarity illusions and the format of hierarchical encodings in memory. *Cognition*, *157*, 321–339. https://doi.org/10.1016/j.cognition.2016.08.016

Penka, D., & Zeijlstra, H. (2010). Negation and polarity: An introduction. *Natural Language & Linguistic Theory*, *28*(4), 771–786. https://doi.org/10.1007/s11049-010-9114-0

Phillips, C., Kazanina, N., & Abada, S. H. (2005). ERP effects of the processing of syntactic long-distance dependencies. *Cognitive Brain Research*, *22*(3), 407–428. https://doi.org/10.1016/j.cogbrainres.2004.09.012

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Potts, C. (2007). The expressive dimension. *Theoretical Linguistics*, *33*, 165–198. https://doi.org/10.1515/TL.2007.011

Pu, Y., Cheyne, D., Sun, Y., & Johnson, B. W. (2020). Theta oscillations support the interface between language and memory. *NeuroImage*, *215*, 116782. https://doi.org/10.1016/j.neuroimage.2020.116782

Regel, S., Gunter, T. C., & Friederici, A. D. (2011a). Isn't it ironic? an electrophysiological exploration of figurative language processing. *Journal of cognitive neuroscience*, *23*(2), 277–293. https://doi.org/10.1162/jocn.2010.21411

Regel, S., Gunter, T. C., & Friederici, A. D. (2011b). Isn't it ironic? An electrophysiological exploration of figurative language processing. *Journal of Cognitive Neuroscience*, *23*(2), 277–293. https://doi.org/10.1162/jocn.2010.21411

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. https://doi.org/10.1162/jocn.2007.19.8.1259

Romero, M. (2017). German discourse particles in questions. An Invited talk at the workshop *Inquisitiveness Below and Beyond the Sentence Boundary* (InqBnB2). University of Amsterdam, December 18th–19th.

Saddy, D., Drenhaus, H., & Frisch, S. (2004). Processing polarity items: Contrastive licensing costs. *Brain and Language*, *90*, 495–502. https://doi.org/10.1016/S0093-934X(03)00470-X

Schneider, J. M., & Maguire, M. J. (2018). Identifying the relationship between oscillatory dynamics and event-related responses. *International Journal of Psychophysiology*, *133*, 182–192. https://doi.org/10.1016/j.ijpsycho.2018.07.002

Shao, J., & Neville, H. (1998). Analyzing semantic processing using event-related potentials. *Newsletter for the Center for Research in Language*, *11*(5), 3–20.

Spotorno, N., Cheylus, A., Van Der Henst, J.-B., & Noveck, I. A. (2013). What's behind a P600? Integration operations during irony processing. *PLoS ONE*, *8*(6), e66839. https://doi.org/10.1371/journal.pone.0066839

Steinhauer, K., Drury, J. E., Portner, P., Walenski, M., & Ullman, M. T. (2010). Syntax, concepts, and logic in the temporal dynamics of language comprehension: Evidence from event-related potentials. *Neuropsychologia*, *48*(6), 1525–1542. https://doi.org/10.1016/j.neuropsychologia.2010.01.013

Sutton, S., Braren, M., Zubin, J., & John, E. (1965). Evoked-potential correlates of stimulus uncertainty. *Science*, *150*(3700), 1187–1188. https://doi.org/10.1126/science.150.3700.1187

Swaab, T. Y., Ledoux, K., Camblin, C. C., & Boudewyn, M. A. (2012). Language-related ERP components. In *The Oxford handbook of event-related potential components* (pp. 397–439). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195374148.013.0197

Theiler, N. (2020). Denn as a highlighting-sensitive particle. *Linguistics and Philosophy*, *44*, 1–40. https://doi.org/10.1007/s10988-019-09290-7

Thurmair, M. (1991). Zum Gebrauch der Modalpartikel ‘denn’ in Fragesätzen. Eine korpusbasierte Untersuchung. In E. Klein, F. Pouradier Duteil, & K. H. Wagner (Eds.), *Betriebslinguistik und Linguistikbetrieb. Akten des 24. Ling. Koll. Bremen, September 1989* (pp. 377–387). de Gruyter. https://doi.org/10.1515/9783111353166.377

Tomasello, R. (2023). Linguistic signs in action: The neuropragmatics of speech acts. *Brain and Language*, *236*, 105203. https://doi.org/10.1016/j.bandl.2022.105203

Tomasello, R., Grisoni, L., Boux, I., Sammler, D., & Pulvermüller, F. (2022). Instantaneous neural processing of communicative functions conveyed by speech prosody. *Cerebral Cortex*, *32*(21), 4885–4901. https://doi.org/10.1093/cercor/bhab522

van Petten, C., & Kutas, M. (1991). Influences of semantic and syntactic context on open- and closed-class words. *Memory & Cognition*, *19*(1), 95–112. https://doi.org/10.3758/BF03198500

Vasishth, S., Brüssow, S., Lewis, R. L., & Drenhaus, H. (2008). Processing polarity: How the ungrammatical intrudes on the grammatical. *Cognitive Science*, *32*(4), 685–712. https://doi.org/10.1080/03640210802066865

Wegener, H. (2002). The evolution of the German modal particle ‘denn’. In I. Wischer & G. Diewald (Eds.), *New reflections on grammaticalization* (pp. 379–393). Benjamins. https://doi.org/10.1075/tsl.49.24weg

Xiang, M., Dillon, B., & Phillips, C. (2009). Illusory licensing effects across dependency types: ERP evidence. *Brain and Language*, *108*(1), 40–55. https://doi.org/10.1016/j.bandl.2008.10.002

Xiang, M., Grove, J., & Giannakidou, A. (2013). Dependency-dependent interference: NPI interference, agreement attraction, and global pragmatic inferences. *Frontiers in Psychology*, *4*, 708. https://doi.org/10.3389/fpsyg.2013.00708

Xiang, M., Grove, J., & Giannakidou, A. (2016). Semantic and pragmatic processes in the comprehension of negation: An event related potential study of negative polarity sensitivity. *Journal of Neurolinguistics*, *38*, 71–88. https://doi.org/10.1016/j.jneuroling.2015.11.001

Yanilmaz, A., & Drury, J. E. (2018). Prospective NPI licensing and intrusion in Turkish. *Language, Cognition and Neuroscience*, *33*(1), 111–138. https://doi.org/10.1080/23273798.2017.1371779

Yurchenko, A., Den Ouden, D.-B., Hoeksema, J., Dragoy, O., Hoeks, J. C., & Stowe, L. A. (2013). Processing polarity: ERP evidence for differences between positive and negative polarity. *Neuropsychologia*, *51*(1), 132–141. https://doi.org/10.1016/j.neuropsychologia.2012.10.028

Zimmermann, M. (2004). Zum ‘Wohl’: Diskurspartikeln als Satztypmodifikatoren. *Linguistische Berichte*, *199*, 253–286.