Storage and Integration in the Processing of Filler-Gap Dependencies:

An ERP Study of Topicalization and *Wh*-Movement in German

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Abstract

We recorded event-related brain potentials (ERPs) during the processing of unambiguous German sentences containing different types of filler-gap dependency. Both topicalization constructions and *wh*-questions were found to elicit a left-anterior negativity (LAN) prior to the processing of the subcategorizing verb, relative to a gap-free control condition. At the subcategorizing verb, sentences containing a *wh*-dependency produced a parietal positivity (P600) relative to topicalization structures. These results support the claim that separable parsing processes are involved in the processing of syntactic dependencies, with working memory based processes being reflected in a LAN, and the relative difficulty of integrating the filler with its subcategorizer reflected in a P600. Integration cost but not memory cost was found to be influenced by the type of filler-gap dependency involved.

Key Words: Sentence processing, ERPs, filler-gap dependencies, *wh*-questions, raising, topicalization, German

1. Introduction

The processing of sentences containing syntactically displaced constituents presents a challenge to the human sentence processor insofar as a dislocated element cannot be integrated into the current parse immediately, but instead must be held in working memory until it can be linked to its subcategorizer, or reconstructed at its canonical structural position. In SVO languages like English, for example, direct objects canonically follow their subcategorizing verbs. During the comprehension of non-canonically ordered sentences such as *wh*-object interrogatives of the type *Which author do you admire?*, however, the fronted *wh*-expression's grammatical function and thematic role cannot be fully determined until a syntactic dependency has been established between *which author* and the verb *admire*, which then allows the reader or listener to identify *which author* as the verb's 'missing' THEME or PATIENT argument. Increasing the distance between a dislocated element (or 'filler') and its subcategorizer (or associated 'gap', such as the vacant object position following *admire* in the example above) has been found to lead to a measurable increase in processing cost (Fiebach et al., *in press*, King & Just, 1991, King & Kutas, 1995, Kluender & Kutas, 1993, Kluender & Münte, 1998, among others).

The temporary storage of a displaced constituent during sentence processing, its retrieval from working memory, and its subsequent integration with its subcategorizer are all assumed to use up a certain amount of processing resources. According to the *Syntactic Prediction Locality Theory* proposed by Gibson (1998), for example, memory cost and integration cost constitute separate components of a sentence's overall processing cost. Memory cost is argued to depend on the number of syntactic predictions being held in working memory at any given point during processing, that is, on the minimum number of syntactic heads required to form a grammatical sentence. Integration cost, on the other hand, is calculated in terms of the number of new

discourse referents intervening between the head of the constituent to be integrated and the head of the host constituent (although Warren & Gibson, 2002, have recently argued for a distance metric based on constituent boundaries rather than heads).

With the majority of filler-gap processing studies having investigated English - a language in which direct object gaps are assumed to be located immediately after the subcategorizing verb - it has usually been difficult to isolate memory cost effects from effects reflecting the relative difficulty of integrating a filler with its subcategorizer.[1] For verb-final languages such as German or Japanese, however, there is evidence that a displaced element is retrieved from working memory and reactivated *before* the subcategorizing verb is encountered (Clahsen & Featherston, 1999, Fiebach et al., *in press*, Nakano et al., 2002), making it possible, in principle, to dissociate empirically memory-based processing cost from the cost of integrating a filler with its lexical subcategorizer. Evidence for the separability of memory and integration cost components comes from a recent study by Fiebach et al. (*in press*) comparing long and short *wh*-dependencies in German. Fiebach and colleagues found evidence that memory cost but not integration cost was influenced by the relative distance between the filler and its associated gap, and that only memory cost interacted with individual working memory capacity. One issue that their study has not been able to resolve, however, is the question of whether distance should be calculated in *linear* terms (i.e., in terms of the number of words or syntactic heads intervening between the filler and the gap), or whether a distance metric that is sensitive to hierarchical phrase structure is more appropriate. If the distance effect is structure-dependent, then we might, for instance,

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[1] A notable exception is McElree's (2000) study of filler-gap dependencies using the *speed-accuracy tradeoff procedure*, which allows for both a filler's availability and its accessibility to be assessed separately.

expect the cost of keeping a filler in working memory to increase if the dependency holds across a clause boundary, even if introducing such a boundary leaves the linear distance between filler and gap unchanged.

Another issue that has not yet been systematically investigated is whether or not the distance effect is modulated by the type of filler-gap dependency involved, such as *wh*-movement versus topicalization. A direct comparison of *wh*-movement and topicalization stuctures is possible in verb-second languages such as German, where the dislocated element appears in the same structural position (i.e., immediately preceding the finite verb or auxiliary) in both cases. In German, object topicalization is also possible across a clause boundary, for instance if the matrix verb is a raising predicate such as *scheinen* 'seem' which takes an infinitival clause as its complement.

The present study aims to address the issues of whether or not the processing cost associated with processing syntactic dependencies is influenced by the type of dependency involved, and/or by the complexity of the intervening structure, by comparing German readers' event-related brain potentials (ERPs) to three types of syntactic dependency: monoclausal *wh*-dependencies, monoclausal topicalization structures, and biclausal topicalization structures involving a raising verb. The following section provides a brief overview of previous results from ERP studies on syntactic dependencies.

2. Event-related potentials and syntactic dependencies

ERPs provide an on-line record of the brain's electrophysiological responses to a particular stimulus. While ERP correlates of language have been described relatively early (see Kutas et al., 2000, for a review), the search for ERP-components related to syntactic processing has begun

with some delay. Over the years, however, two phenomena, left anterior negativities (LANs) and a somewhat later parietal positivity (P600, or syntactic positive shift), have been replicated numerous times in experiments manipulating syntactic factors.

Kluender & Kutas (1993) and Kluender & Münte (1998), investigating subject and object *wh*-questions, found that the object questions were associated with a larger left anterior negativity at the filler and gap positions, an effect that has been interpreted to reflect the greater working memory load associated with object questions in which the filler has to be kept active for a longer time. The above results suggest that both the temporary storage of a displaced constituent and its retrieval from working memory upon encountering a gap may give rise to LAN effects. Similar findings have been reported by Fiebach et al. (*in press*), who observed a sustained LAN effect elicited by indirect object versus subject *wh*-questions starting about 400 ms after the onset of the first prepositional phrase following the *wh*-pronoun in sentences of the type *Karl fragt sich, wen [PP PP] der Doktor gerufen hat* ('Karl is asking himself whom [PP PP] the doctor has called'), and terminating at the subject noun phrase preceding the verb. Other results that can be viewed as supporting the working memory account of the LAN come from studies using embedded subject and object relative clauses (King & Kutas, 1995, Müller et al., 1997) or sentences using temporal terms (before/after) in the initial position of sentence (Münte et al., 1998b). More recently, Matzke et al. (*in press*) have found two different left anterior negativities in a study on canonical and non-canonical word order in German. The first one, having a frontocentral maximum (electrode site Fc1), was shown for sentence initial articles in sentences starting with masculine noun phrases. Object noun phrases (*den Mann* 'the-ACC man') elicited a LAN when compared to subject noun phrases (*der Mann* 'the-NOM man'). A frontotemporal (maximum at F7) LAN was found at a later position of the sentence at which the second noun phrase was presented. These

two effects were tentatively interpreted as reflecting storage in, and retrieval from, verbal working memory. A large number of studies have also reported left anterior negativities in response to syntactic incongruencies such as word category violations (Friederici et al., 1996, among others) or morphosyntactic incongruencies (e.g., Münte et al., 1998a).

The second component which has been associated with syntactic factors is a parietal positivity, variously termed P600 (Osterhout & Holcomb, 1992) or syntactic positive shift (Hagoort et al., 1993) and usually having a peak latency of about 600 ms relative to the eliciting event.[2] The P600 has been observed in response to a variety of different syntactic anomalies including morphosyntactic violations, phrase structure violations, and subjacency violations, as well as to dispreferred but grammatically well-formed ('garden-path') constructions (Osterhout et al., 1994, McKinnon & Osterhout, 1996) and to syntactically ambiguous sentences (Osterhout & Holcomb, 1992, Friederici, 1995). It has been proposed that the amplitude of the P600 reflects 'cost of syntactic processing', with higher processing costs being correlated with a higher amplitude (Osterhout et al., 1994: 18). According to this view, the P600 is elicited by syntactic anomalies resulting from the perceiver's own parsing preferences (as for example in garden-path sentences) as well as from outright ungrammaticality. Friederici and her collaborators (see, for example, Friederici & Mecklinger, 1995, Friederici et al., 1996) have specifically linked the P600 to the second or reanalysis stage of two stage parsing models (Frazier, 1987, Gorrell, 1995). A P600 effect has also been observed in the processing of syntactically well-formed and unambiguous sentences. Fiebach et al. (*in press*), Kaan et al. (2000), and Phillips et al. (2001) have argued that the P600 may reflect the relative difficulty of integrating a displaced constituent into the verb

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[2] Components peaking as early as 345 ms have also been linked to the P600, though (Mecklinger et al., 1995).

phrase, and Featherston et al. (2000) found a P600 effect elicited by raising constructions. All of this is not to say that the P600 represents a component exclusively sensitive to syntactic processing or even language. Indeed, several results suggest that this component might be an instance of the generic P300 component (see Coulson et al., 1998). What is critical here is that the P600 has been shown to reliably covary with syntactic factors.

3. The present study

Several properties of German make this language a suitable candidate for investigating the separability of memory cost and integration cost, as well as for a direct comparison of different types of filler-gap dependency. As to the first point, it has been suggested that when processing a verb-final language, the parser will begin constructing the VP before the verb has been processed (compare, among others, Bader & Lasser, 1994, Crocker, 1994, Inoue & Fodor, 1995, Yamashita, 1997). On the assumption that syntactic dependencies will be established as soon as grammatically possible (the *active filler strategy*; Frazier & Clifton, 1989), this would seem to imply that displaced arguments are retrieved from working memory and reconstructed at the hypothesized gap position *before* the subcategorizing verb is encountered. Determining a displaced constituent's grammatical function in the absence of its lexical subcategorizer is facilitated by the fact that noun phrases are overtly case-marked. For illustration, consider a *wh*-object question such as (1) below.

(1) *Welchen Scherz hat der Lehrer dem Schüler verziehen*?
which-ACC joke has the-NOM teacher the-DAT pupil forgiven?
'Which joke did the teacher forgive the pupil?'

In (1), the accusative case marking on *welchen Scherz* indicates that the *wh*-filler grammatically functions as a direct object. That is, rather than having to keep the filler in working memory until the verb has been processed, the parser can retrieve the filler at the beginning of the verb phrase (i.e., as soon as the subject *der Lehrer* has been received) in order to reconstruct it as a preverbal object. In short, it is plausible to assume that in German, filler-gap dependencies of the above type can be established prior to the processing of the subcategorizing verb, on the basis of structural knowledge and morphosyntactic properties of the filler itself. If the LAN component that has frequently been observed in the processing of *wh*-dependencies does indeed reflect memory cost, then we might expect sentences of the above type to produce a LAN effect at the beginning of the verb phrase. For the filler to be assigned a thematic or participant role, however, it is necessary that the subcategorizing verb has been received. Hence, if the cost of integrating a filler with its subcategorizer is reflected in a P600 component, we might expect to observe a P600 (but not a LAN) effect at the verb. Using ditransitive verbs enables us to further increase the distance between the subject and the verb by inserting an additional, dative-marked object NP before the verb as in (1) above.

The verb-second property of German moreover allows us to compare various types of filler-gap dependency directly. Object topicalization structures such as (2) below, for example, are structurally identical to *wh*-object questions such as (1) above, due to the fact that in German main clauses the sentence-initial constituent must always be followed immediately by the finite verb or auxiliary, regardless of whether or not the sentence is interrogative.

(2) *Den Scherz hat der Lehrer dem Schüler verziehen.*
the-ACC joke has the-NOM teacher the-DAT pupil forgiven
'The joke, the teacher forgave the pupil.'

From a linguistic point of view, the main difference between *wh*-movement and topicalization is that *wh*-movement (in *wh*-raising languages such as English or German) is a mandatory operation which ensures that a sentence is interpreted as interrogative. The surface position of a fronted *wh*-operator is thought to correspond to its scope position at the level of semantic interpretation. Topicalization, by contrast, is a *stylistic* operation motivated by considerations of focussing or emphasis, and topicalized (non-quantificational) constituents differ from *wh*-operators in that they do not normally carry any quantificational force. Both types of dislocated element must be linked to their subcategorizer, or reconstructed at their base position, in order to receive a thematic role, but in the case of *wh*-dependencies it is vital that the operator or *wh*-part of a moved *wh*-expression is retained at the derived position, so as to ensure that the sentence can be assigned the intended interpretation (cf. [3c]).

(3) a. [*Which book*]$_i$ were you reading t_i last night?
b. [*WHICH* ~~*book*~~] were you reading [~~*which*~~ *BOOK*] last night?
c. [For which *x*, *x* a book] [you were reading *x* last night]

Given the need for a *wh*-expression to be split into an 'operator' and a 'core' part for the purpose of semantic interpretation, it is conceivable that during sentence comprehension, splitting up and integrating (the core part of) a moved *wh*-expression with its subcategorizer requires somewhat

more processing effort than does the integration of a non-quantificational topicalized constituent. Thus, if the type of syntactic dependency affects the relative difficulty of establishing a filler-gap dependency during on-line processing, we would expect to find this reflected in the relative size of the predicted ERP effects.

Finally, note that object topicalization is also possible in sentences that contain a raising verb such as (4) below. Even though in this case, the object has been extracted from an embedded infinitival clause rather than from the main clause, the number and relative ordering of the words intervening between the topicalized object and its subcategorizer (the verb *verzeihen* 'forgive') is identical to that of the two previous examples.

(4) *Den Scherz scheint der Lehrer dem Schüler verziehen zu haben.*
the-ACC joke seems the-NOM teacher the-DAT pupil forgiven to have
'The joke, the teacher seems to have forgiven the pupil.'

The raising construction in (4) differs from both the *wh*-object movement and object topicalization constructions in (1) and (2) in that the raising verb *scheinen* 'seem' selects a clausal complement, thus introducing an additional level of linguistic structure intervening between the filler and its subcategorizer. By comparing syntactic dependencies which span the same linear distance while involving different degrees of structural complexity, we should be able to ascertain whether memory cost and/or integration cost are influenced by the hierarchical complexity of the intervening linguistic structure.

In our experiment, we investigated the processing of sentences of the three types introduced above, with the distance between the filler and the gap being increased by the addition of a

padding phrase after the finite verb or auxiliary in second position in all three 'gap' conditions. The predictions are summarized below:

i. Sentences containing an object gap should elicit a LAN relative to a gap-free control condition *before* the subcategorizing verb is encountered.

ii. If memory cost is influenced by the type of syntactic dependency, then *wh*-movement should elicit a more pronounced LAN than topicalization structures.

iii. If memory cost is influenced by the structural complexity of the intervening material, then raising sentences should produce a larger LAN effect than all other conditions (due to the additional structural complexity introduced by the presence of an intervening clause boundary and/or the additional need for applying subject-to-subject raising).

iv. If integration difficulty is influenced by the type of filler to be integrated, then *wh*-movement should elicit a P600 compared to topicalization sentences at the subcategorizing verb.

v. If integration difficulty is influenced by the structural complexity of the intervening material, then raising sentences should produce a P600 compared to the two monoclausal constructions.

4. Methods and Materials

Subjects

Nineteen healthy young right-handed native speakers of German were recruited at the Medical School of Hanover, Germany (9 women, age range 22 to 26 years, mean 24.5). Vision was normal or corrected to normal. They gave their informed consent to participate in two sessions separated by several days lasting about 2.5 hours each. Data of one additional subject was discarded because of excessive blinking.

Stimuli

A total of 140 sentence quadruplets were constructed as in the following example:[3]

(5) ***Raising & object topicalization (R)***

Den Abschied scheint, da die anderen Kollegen schon wieder tuscheln,
the saying-goodbye seems as the other colleagues already again whisper

die Krankenschwester einem befreundeten Jungarzt erleichtern zu wollen.
the nurse a friend junior.doctor make.easy to want

'The saying-goodbye, the nurse seems to want to make easier for a junior doctor friend of hers, as the other colleagues are already whispering again.'

[3] The full set of materials can be made available by the authors upon request.

(6) ***Wh-object movement (W)***

Welchen Abschied wird, da die anderen Kollegen schon wieder tuscheln,

which saying-goodbye will as the other colleagues already again whisper

die Krankenschwester einem befreundeten Jungarzt erleichtern wollen?

the nurse a friend junior.doctor make.easy want

'Which saying-goodbye is the nurse going to want to make easier for a junior doctor friend of hers, as the other colleagues are already whispering again?'

(7) ***Long object topicalization (L)***

Den Abschied wird, da die anderen Kollegen schon wieder tuscheln,

the saying-goodbye will as the other colleagues already again whisper

die Krankenschwester einem befreundeten Jungarzt erleichtern wollen.

the nurse a friend junior.doctor make.easy want

'The saying-goodbye, the nurse is going to want to make easier for a junior doctor friend of hers, as the other colleagues are already whispering again.'

(8) ***Short object topicalization (S)***

Den Abschied bedauert die Anstaltsleiterin, da Hans charmant ist und
the saying-goodbye regrets the superintendent as Hans charming is and

die Krankenschwester einem befreundeten Jungarzt nachweint.
the nurse a friend junior.doctor after.cries

'The saying-goodbye, the superintendent regrets, because Hans is charming and the nurse is bemoaning the loss of a junior doctor friend of hers.'

The sentence quadruplets were constructed such that the words at positions 11-15 were always the same (in this case, *die Krankenschwester einem befreundeten Jungarzt*). For the construction of the three gap conditions (5)-(7), 70 ditransitive verbs were used in the main clause (or the embedded clause, in the raising condition), each of which was used twice. To increase the distance between the filler and the gap, an adjunct clause was inserted after the finite verb or auxiliary as a 'padding' phrase. The adjunct clauses were introduced by different words (*da* 'as', *weil* 'because', *während* 'while', *sobald* 'as soon as', etc.) and were always seven words long. None of the object noun phrases in the sentence initial position was used more than twice. All sentence-initial object NPs were masculine in gender, and were unambiguously marked for accusative case.

The control condition (8) also involves object topicalization, but crucially, the filler-gap dependency here will be completed upon encountering the matrix verb (*bedauern* 'regret'), so that contrary to the three gap conditions in (5)-(7), no filler needs to be retrieved from working

memory during the processing of the noun phrase *die Krankenschwester* or any of the following words, all of which form part of the second of two conjoined adjunct clauses.

Each subject saw 140 sentences (35 of each type) in each of the two sessions. Thus, of each sentence quadruplet, a subject saw two of the four versions, one in session 1 and one in session 2. By constructing four different scenarios and by systematically changing the order of experimental blocks, it was ensured that across subjects each sentence was seen equally often.

Sentences were presented word by word (duration 300 ms, stimulus-onset-asynchrony 500 ms) in yellow letters against a blue background in the middle of a video monitor. After each critical sentence a pause of 2000 ms occurred after which a test sentence (e.g., *Die Krankenschwestern tuscheln?* 'The nurses are whispering?') was shown, which had to be verified by the subject by pressing one of two buttons (true/false statement). This test sentence was presented for 4000 ms after which the screen again went blank for 5000 ms before the next critical sentence was presented.

Recording and analysis

EEG was recorded from all 19 standard scalp-sites of the 10/20 system plus 10 additional sites (Fz, Cz, Pz, Fp1/2, F3/4, C3/4, P3/4, O1/2, F7/8, T3/4, T5/6, Fc1/2, Fc5/6, Cp1/2, Cp5/6, PO1/2) using tin electrodes mounted in an electrode cap with reference electrodes placed at the mastoid processes. The biosignals were recorded against a reference electrode on the scalp (C1) and rereferenced off-line to the algebraic mean of the activity at the two mastoid processes. Additional electrodes were affixed at the right external canthus and at the right lower orbital ridge to monitor eye movements. The biosignals were amplified with a bandpass from 0.01 to 70 Hz, digitized at 250 points per second and stored on magnetic disk. Artifact rejection was

performed by an automated procedure using individualized amplitude criteria on the scalp channels. In addition, eye-blink correction was achieved using a spatial filter algorithm implemented by Dale (1994). Averages were computed for 2048 ms epochs including a 200 ms prestimulus baseline. The waveforms were quantified by mean-amplitude measures in the time windows specified in the result section. These data were subjected to repeated measures analyses of variance. As mentioned above, previous ERP studies of syntactic processing have revealed two main components: a left anterior negativity (LAN) with a maximum at left frontotemporal electrode-sites and a posterior later positivity (P600) with a maximum at parietal sites. The LAN was consequently quantified by mean amplitude measures for F3, F7, Fc5 electrode sites (time-windows: see below), while a possible P600 effect was assessed by measuring the mean amplitudes for electrode sites P3, P4, Pz. The analyses were conducted in two steps: First, overall ANOVAs were computed with all four conditions as levels of the factor Condition (R, W, S, L). To elucidate main effects of this factor additional pairwise comparisons were conducted. The Huynh-Feldt correction for inhomogeneities of covariance was applied whenever applicable. Reported are the original degrees of freedom and the corrected p-values.

5. Results

We examined the ERP effects at the beginning of the subject noun phrase at position 11 (e.g., at *die Krankenschwester* in example [5] above), at the beginning of the dative-marked object noun phrase at position 13 (e.g., at *einem befreundeten Jungarzt* in example [5]), as well as at the subcategorizing verb at position 16 (e.g., at *erleichtern* in example [5]).

ERP effects at the subject noun phrase

The general ERP effects of all scalp sites observed at the subject noun phrase (position 11) in the present task are illustrated in Figure 1 for conditions R and S. Superimposed on the exogeneous waveforms produced by the word-stimuli is a more negative-going waveform for the R-condition starting about 400 ms after the beginning of the critical phrase. This effect has a maximum at left fronto-temporal electrodes (F7, Fc5, F3) and can be identified as an instance of the left anterior negativity (LAN).

//INSERT FIGURE 1 ABOUT HERE//

In Figure 2, the pairwise comparisons for the four experimental conditions (R, W, L, S) are shown for the left fronto-temporal electrode sites and the midline parietal site (Pz). With regard to the level of negativity over the left fronto-temporal scalp, this figure shows the following hierarchy:

$$R > (W = L) > S$$

That is, all three gap conditions produced a LAN relative to the gap-free control condition, with the raising condition showing a somewhat greater negativity than the other two gap conditions. Statistically, this was reflected in a main effect of the factor Condition in the overall ANOVA in the 700 to 1100 ms time-window ($F[3,54]=6.9$, $p<0.01$).

//INSERT FIGURE 2 ABOUT HERE//

The pairwise comparisons revealed that the following contrasts were significant at the $p<0.05$ level: R/S, W/S, L/S. While the raising condition appeared to produce a larger negativity than both the W and L conditions, these comparisons did not attain significance (R/L: $p=0.31$; R/W: $p=0.12$). The scalp distribution of the left anterior negativity is demonstrated by subtracting the waveforms of the S-condition from all other conditions (see Figure 3).

//INSERT FIGURE 3 ABOUT HERE//

With regard to the P600 component, inspection of the data of the Pz electrode, the site usually representing the maximum of the P600 does not reveal any systematic differences. Likewise, an ANOVA performed on P3, P4, Pz sites in the time-window 700–1100 ms did not reveal a main effect of Condition ($F(3,54)=2.81$). In addition, none of the pairwise comparisons attained significance at the $p<0.05$ level.

ERPs at the dative noun phrase

ERPs at the dative-marked object NP at position 13 are illustrated in Figure 4. Visual inspection of the waveforms reveals that none of the comparisons yielded effects at the left fronto-temporal or parietal electrode sites. This was corroborated by the statistical comparisons that did not reveal any main or interaction effects of stimulus condition for frontal or parietal electrode sets.

//INSERT FIGURE 4 ABOUT HERE//

ERP effects at the verb

Further analyses were carried out for the lexical verbs at position 16, illustrated in Figure 5. As the words that appeared in the S-condition at this position were different from the ditransitive verb used in the gap conditions, data from the S-condition were dropped from the analysis.[4] Frontally, an early left negativity was seen for both the *wh*-object movement (W) and the long topicalization (L) conditions versus the raising condition (R). In the overall ANOVA (mean amplitude 300-500 ms, F3, F7, Fc5 sites) this negativity was reflected by a main effect of Condition ($F(2,38)=10.81$, $p(HF)<0.0002$), with the pairwise comparisons of R/L attaining significance ($p<0.0001$) and R/W attaining marginal significance ($p=0.07$).

//INSERT FIGURE 5 ABOUT HERE//

[4] While the *[NP-NOM] [NP-DAT]* sequence in the preverbal region (positions 11-15) was kept identical in all four conditions, a variety of both monotransitive 'dative' verbs and ditransitives were used in the S-condition, which appeared at or after position 16. As the use of ditransitive verbs in gap-free sentences requires the insertion of an additional NP (the direct object) before the verb, a direct comparison with the subcategorizing verb in the three gap conditions would have been precluded even if we had used the same verbs in the control condition.

In addition, a parietal positivity (P600) was present for the W-condition relative to the R and L conditions. In the overall ANOVA (mean amplitude 700-900 ms; P3, P4, Pz sites) a main effect of condition was obtained ($F(2,38)=7.43$, $p(HF)<0.002$) with the pairwise comparisons of R/L ($p<0.0007$) and R/W ($p<0.04$) attaining significance.

6. Discussion

The present study produced three main results:

- a LAN effect elicited by the three gap conditions (R, W, L) versus the control condition (S) at the subject noun phrase following the adjunct clause;
- a P600 effect elicited by the *wh*-object movement (W) versus the raising (R) and long topicalization (L) conditions at the subcategorizing verb;
- a frontal negativity elicited by the two monoclausal gap conditions (W & L) versus the raising (R) condition at the verb.

The fact that qualitatively different ERP effects were observed at different syntactic positions suggests that separable parsing processes are involved in the processing of filler-gap dependencies. In the following, the ERP effects observed at the subject noun phrase and at the subcategorizing verb will be discussed separately.

ERP effects at the subject noun phrase

Our finding that the LAN effect occurred *before* the participants had encountered the subcategorizing verb supports the idea that the LAN reflects working memory cost, as has

previously been proposed by Fiebach et al. (*in press*), Kluender & Kutas (1993), Kluender & Münte (1998), and Phillips et al. (2001), among others. As mentioned above, it is plausible to assume that in verb-final languages such as German, the parser begins (re-)constructing the verb phrase as soon as possible and before the verb has been processed. In our materials, the appearance of the subject noun phrase following the padding clause appears to have triggered the filler's retrieval from working memory. This conclusion is supported by the fact that the LAN observed at the preverbal nominative NP did not extend over the following dative NP. While the filler may have been (tentatively) associated with a particular structural position or grammatical function at this point, integrating it with its subcategorizer - including thematic role assignment - will not normally be possible until the actual verb has been received. The size of the observed LAN was not influenced by the type of filler (*wh*-object movement vs. object topicalization), indicating that the working memory cost incurred by processing filler-gap dependencies is independent of the specific type of syntactic dependency involved. The larger LAN effect elicited by the raising condition, however, could be taken to indicate that additional structural complexity increases memory cost, even if the number of words intervening between the filler and the gap is kept the same. If this is correct, then it would seem that a distance metric that takes into account hierarchical phrase structure is more appropriate than a metric based on linear distance alone.

ERP effects at the verb

The P600 effect elicited by the *wh*-object movement condition at the subcategorizing verb supports previous claims by Kaan et al. (2000), Fiebach et al. (*in press*), and Phillips et al. (2001) to the effect that the P600 reflects integration cost.[5] Our finding that the *wh*-condition produced a

[5] Whereas previous studies on English have also found a P600 at, or immediately after, the

larger parietal positivity than did the other two gap conditions moreover indicates that integrating a *wh*-filler with its subcategorizer is computationally more costly than integrating a topicalized constituent, irrespective of the structural complexity of the intervening material. As outlined above, integration cost may be higher in the *wh*-movement condition because in addition to semantically integrating the filler with its subcategorizer, an operator-variable dependency must be upheld at the same time for the sentence to be assigned the correct interpretation.

The frontal negativity produced by the two monoclausal gap conditions (W & L) versus the raising condition (R) is likely to reflect end-of-sentence 'wrap-up' processes. Note that for both the W and the L conditions, the sentence might be considered grammatically complete after the subcategorizing verb (e.g., *erleichtern*) has been received. Although our materials contained an additional modal verb following the main verb, its presence is not in fact grammatically required. With raising verbs selecting an infinitival clause as their complement, on the other hand, the sentence cannot possibly be deemed complete until the infinitival particle *zu* 'to' has been received, which in our materials followed the subcategorizing verb. ERP responses to sentence-final words have been found to be different from those to embedded words (Friedman et al., 1975), with several studies having reported a sentence-final negativity (Hagoort et al., 1993,

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verb (Kaan et al., 2000, Phillips et al., 2001), Fiebach et al. (*in press*) report a late centro-parietal positivity elicited by the preverbal noun phrase in German indirect *wh*-questions. These differences with respect to the occurrence of the late positivity may be attributable to methodological differences. Note, for example, that while Fiebach et al. compared ERPs to nominative (=subject) and accusative-marked (=object) NPs, we compared ERPs to noun phrases that were morphosyntactically identical in all conditions.

McKinnon & Osterhout, 1996, Osterhout & Mobley, 1995, among others) that has been linked to semantic interpretation processes (Osterhout & Holcomb, 1992).

7. Conclusion

Our results add support to the claim that separate parsing processes are involved in the processing of filler-gap dependencies, with the working memory cost incurred by storing and retrieving a filler being reflected in a left-anterior negativity that occurred prior to the processing of the subcategorizing verb, and the cost of integrating a filler with its subcategorizer being reflected in a P600. Moreover, our results suggest that memory cost but not integration cost is affected by the syntactic complexity of the intervening material. Conversely, the cost of integrating a filler with its subcategorizer, but not memory cost, was found to be influenced by the type of syntactic dependency involved (*wh*-movement vs. topicalization). Taken together, these findings provide further evidence for the separability of memory cost and integration cost components in parsing.

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Figure Captions

Figure 1: Grand average (n=19) ERPs at position 11 (subject noun phrase) of the R and S conditions. Most prominent over left frontal areas (electrodes Fc5, F3, F7), the waveforms from the R-condition are more negative than those from the S-condition. The effect has an onset of about 400 ms and extends beyond the end of the epoch shown.

Figure 2: Pairwise comparisons of the different conditions at position 11. For the left frontal electrode sites a more negative-going ERP starting approximately at 400 ms was seen for the R, L, and W conditions relative to the S-condition. This effect was most prominent for the R-condition.

Figure 3: Illustration of the scalp topography of the negativity at the subject noun phrase. Spline-interpolated isovoltage maps are based on the mean voltage (700-1100 ms) of the difference waves obtained by subtracting the ERPs from the S-condition from those of the conditions of interest.

Figure 4: Pairwise comparisons of the different conditions at position 13 (dative noun phrase). No reliable effects or interactions were observed at the relevant electrode sites.

Figure 5: Pairwise comparisons of the three gap conditions at position 16 (verb). A frontal early negativity can be observed for the W and L-conditions relative to the R-condition in the 300-600 ms range. For the W-condition a parietal positivity (P600) is seen relative to the other conditions with an onset latency of about 700 ms.

Figure 1

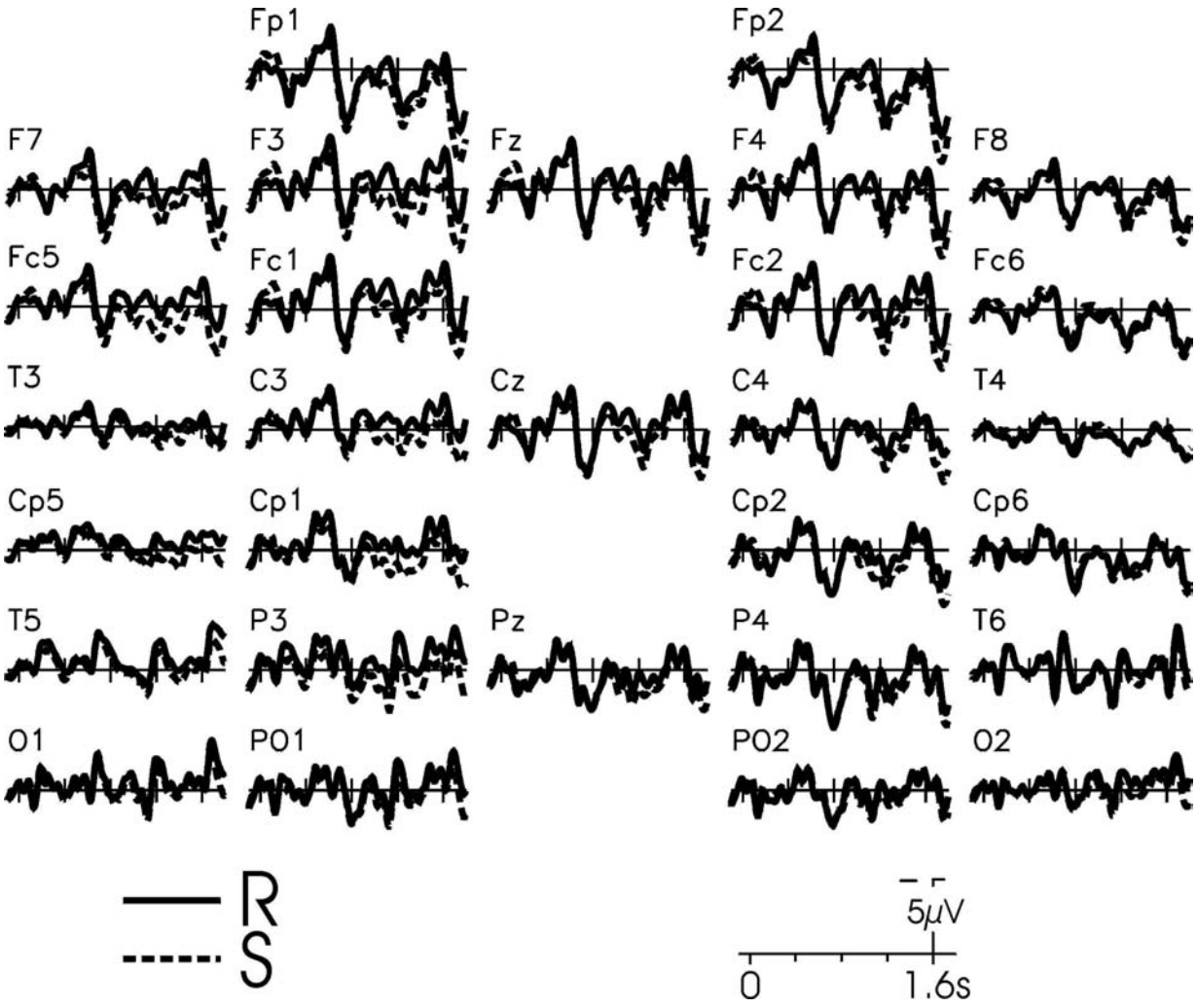
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Figure 2

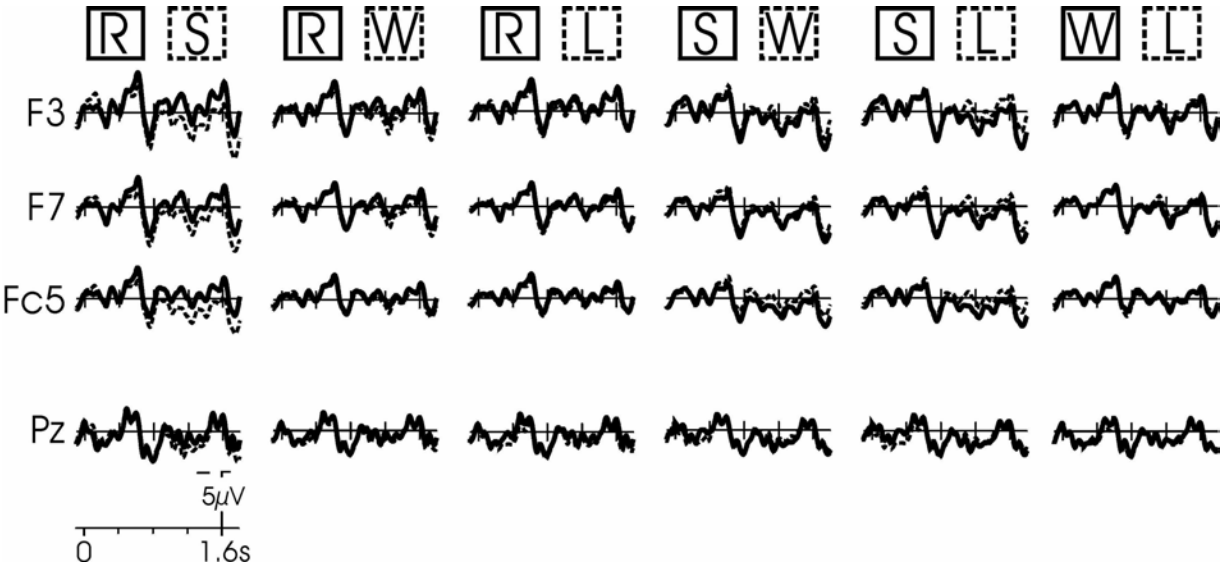

Figure 3

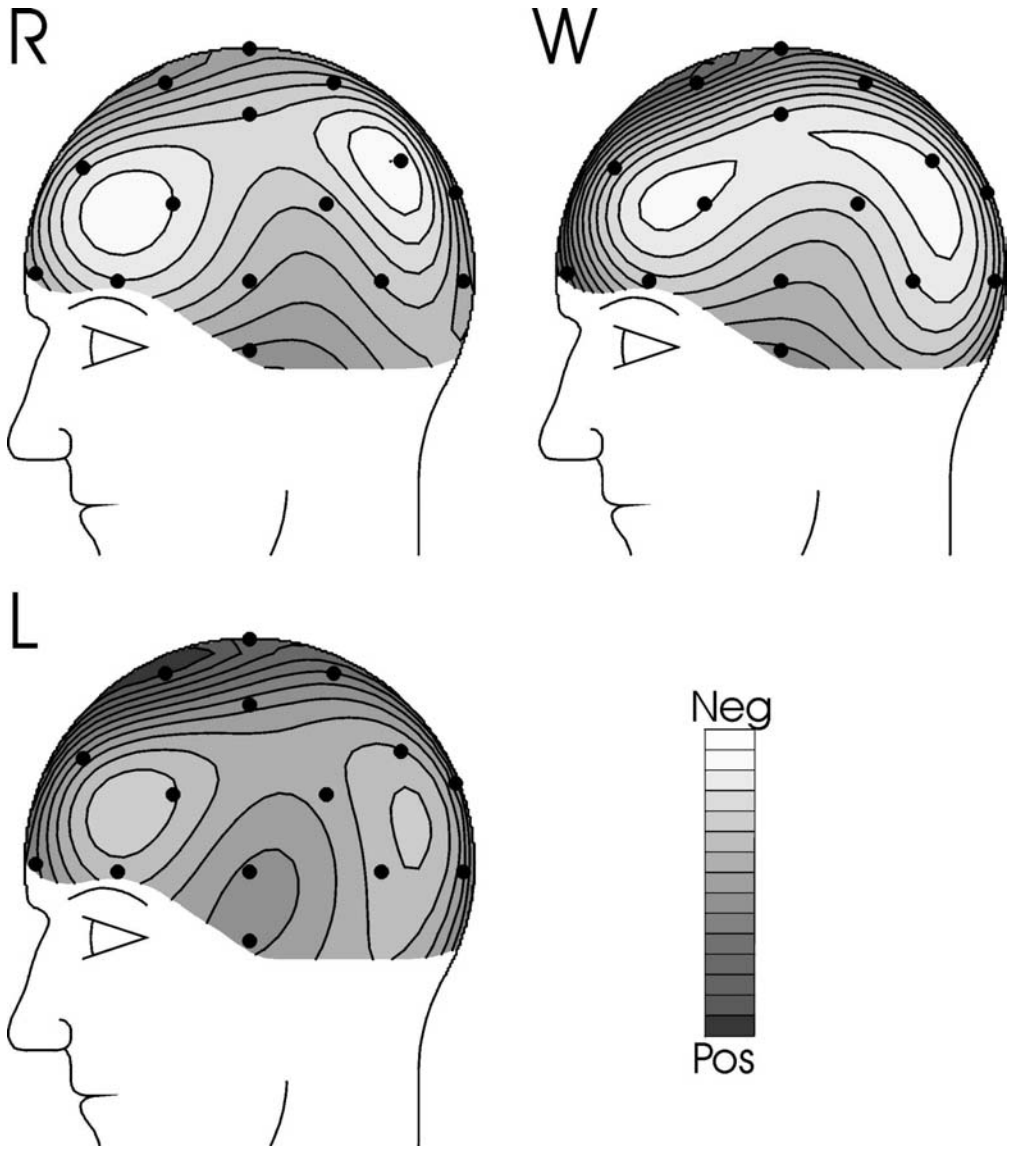

Figure 4

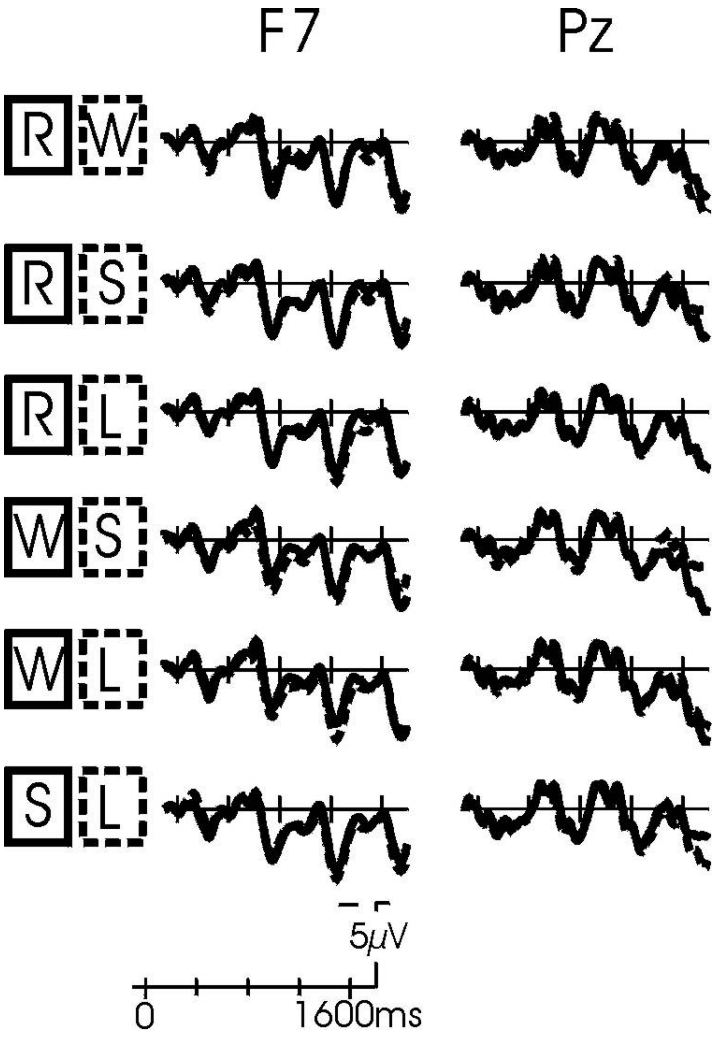

Figure 5