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Working memory constraints on syntactic ambiguity resolution as revealed by electrical brain responses

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Abstract

Parsing strategies in temporarily ambiguous sentences were investigated in readers with different sentence memory capacities using event-related brain potentials (ERPs). Readers with a high memory span as well as readers with a low memory span were required to read subject and object relative sentences which were either ambiguous until the last word (late disambiguation) or were disambiguated by case marking either the clause initial pronoun (immediate disambiguation) or the noun phrase following it (early disambiguation). ERPs registered during sentence reading elicited the following effects: In the late disambiguation condition, high span readers, but not low span readers, displayed a more positive going wave at the disambiguating number marked auxiliary for the object relative sentences than for the subject relative sentences. This positivity is taken to reflect processes of revision that become necessary at the disambiguating element if the initial structure considered is a subject relative clause. When case marking was available in the clause initial at the relative pronoun, both high and low span readers showed a positivity at the disambiguating element for the object relative sentences, suggesting the immediate use of case marking information for revision. When case marking was available in the noun phrase following an ambiguous pronoun both groups showed no clear effect of revision at the disambiguating element, but only at the sentence final number marked auxiliary. This non-immediate use of the case marking information seems to be due to an inherent ambiguity in the German case marking system

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which interacts with the disambiguating element's position in the sentence. The combined data indicate that morphological information can be used immediately by high and low span readers to resolve syntactic ambiguity during sentence processing whenever the information given is clearly unambiguous. In addition they suggest that possible processing differences in ambiguity resolution between high and low span readers may only appear when the ambiguous regions are long.

Keywords: Memory; Language; Event-related potentials; Ambiguity

1. Introduction

One of the issues widely discussed in different models of language comprehension is the type of process involved when resolving temporary linguistic ambiguity. In an early model of language parsing called the Garden-path Model, Frazier (Frazier, 1978; Frazier and Fodor, 1978) assumed that when confronted with a syntactically ambiguous structure the parser generally computes only the simplest structure justified by the input, considering alternative structures only after the subsequent input fails to support the structure initially built. The model is called garden-path model because it predicts that when processing structurally ambiguous sentences (e.g. *the horse raced passed the barn fell*) readers only consider one, namely the simplest interpretation. That means that the reader is 'led down the garden-path' in those cases in which the alternative interpretation is required. More recent studies discussed the possibility that the parser might process all possible structures in parallel (e.g., Gorrell, 1987; Hickok, 1993).

Parallel to this discussion of whether one or all possible structures are considered by the parser on-line, Just and Carpenter (1992) introduced a model in which parsing strategies depend on individual differences in working-memory capacity. In particular, the Capacity Constrained Parsing Model (MacDonald et al., 1992) holds that the individual's working-memory capacity constrains the processing of syntactic ambiguity. When presented with a syntactic ambiguity the reader initially constructs multiple representations. During subsequent processing, however, readers with a low memory capacity (low span readers) are likely to abandon representations that initially received a lower activation level, as a result of either being of low frequency, pragmatically implausible or syntactically highly complex, whereas readers with a high memory capacity (high span readers) in contrast, are more likely to maintain multiple representations for longer periods. This result was particularly seen for short sentences (10–12 words) but not for longer sentences (13–15 words). This was taken to indicate that high span readers do not maintain multiple interpretations indefinitely. Results from an earlier eye fixation study (Carpenter and Daneman, 1981), however, suggested that an unselected group of readers immediately selected and retained only a single representation when encountering an ambiguity. MacDonald et al. (1992) suggested that this result may be due to the amount of high span readers in this earlier experiment.

Recently, Waters and Caplan (1996a,b) questioned the capacity theory of comprehension as formulated by Just and Carpenter (1992) on empirical and theoretical grounds. In exploring the relationship between working memory capacity and the processing of temporarily ambiguous sentences, they found no differences between subjects with different working memory spans for the processing of garden-path sentences in an off-line sentence acceptability task.

Thus, it seems that the issue of whether or not readers compute multiple representations for a given syntactically ambiguous input, and to what extent these two different possible processing strategies depend upon the reader's working memory capacity is unresolved. The various studies investigating this issue in unselected or selected groups have used different experimental paradigms and stimulus materials (for an early overview see Garrett, 1970; for a more recent critical review see Frazier, 1995). Several factors may contribute to the variation across studies. First, it could be relevant whether effects are measured off-line or on-line. Off-line measurements may capture a processing phase for which both the Garden-Path and the Capacity Constrained Model predict, for different reasons, the immediate availability of non-preferred structures for high and low span readers. According to the Garden-Path Model clear effects of preferential structure building and reanalysis should be observed only during the initial parsing stage that is most likely to be captured by on-line measures (Frazier, 1995). Second, the actual length of the ambiguous region may be an important factor. The Capacity Constrained Model as well as parallel models maintain that readers may keep multiple structures active over short ambiguous regions, but may abandon less preferred structures when ambiguous regions are long. The length of the ambiguous region, moreover, may also interact with the reader's individual working memory capacity.

The present paper investigates the processes of syntactic ambiguity resolution and, thereby, the models of language parsing discussed above, using an on-line measure, namely event-related brain potentials (ERPs), as well as a clearly off-line measure, namely question answering performance with accuracy as the dependent variable. To evaluate the influence of working-memory capacity on ambiguity resolution, readers were assigned to a high span and a low span group. In addition, the influence of working memory on the length of the ambiguous region was investigated with material constructed to allow disambiguation either early or late in the sentence. Syntactic ambiguity was realized in German subject and object relative clauses. These are temporarily ambiguous when noun phrases and relative pronouns are ambiguously case marked (feminine) compared to when they are not (masculine). Table 1 displays the German article system which is identical to the relative pronoun system.

As can be gathered from Table 1 the form *die* carries an ambiguity for case (nominative vs accusative for feminine singular and for all plural forms) and at the same time for number (singular vs plural for feminine) as well as for syntactic gender (feminine plural vs masculine plural vs neuter plural). A clear case disambiguation, however, is present for singular masculine. This difference between ambiguous case (nominative/accusative) in the article/relative pronoun system for

feminine (*die*) and unambiguous case marking for singular masculine (*der*/*den*) in German is used to examine the processing of subject-object ambiguous and unambiguous structures. In sentences (1) and (2) of Table 2 the relative pronoun form (*die*) is ambiguous as it marks feminine nominative and feminine accusative case in both singular (1a, 2a) and plural (1b, 2b). The same holds true for the article form (*die*) in the noun phrase following the relative pronoun (compare Table 1). Since both German subject and object relative clauses display a verb-final (NNV) word order, the correct structure in sentences (1) and (2) can only be disambiguated by the number marking information of the auxiliary in sentence final position, thus creating a long ambiguous region (hereafter: late disambiguation). The ambiguous region is reduced in sentences (3) and (4) where the article in the masculine noun phrase following the pronoun was morphologically marked either for nominative case (in (3): *der*) or for accusative case (in (4): *den*) (hereafter: early disambiguation). Ambiguity is absent in the relative clause sentences (5) and (6) due to immediate disambiguation by the clause initial case marked relative pronoun (nominative: *der*, accusative: *den*) (hereafter: immediate disambiguation).

Previous studies investigating the processing of subject-object ambiguous structures have shown a strong tendency to interpret ambiguous phrases within a subject-first structure in Dutch (Frazier, 1987; Frazier and Flores d'Arcais, 1989), in Italian (De Vincenzi, 1991) and in German (e.g., Konieczny et al., 1994; Schriefers et al., 1995; Schlesewsky et al., 1996; Meng and Bader, 1997). These studies, however, were carried out with unselected groups. Predictions for groups selected for their working memory capacity are different for the Garden-Path model (Frazier, 1978, 1995) and the Capacity Constrained Model (MacDonald et al., 1992). According to Frazier (1995) possible differences between high span and low span readers are attributable to the individual subject's motivation and thus are of no principled interest for the Garden-Path Model. Valid predictions for the present experiment can, therefore, be formulated only for high span readers. The prediction with respect to the sentence material in the present study is that high span (motivated) readers, should show an initial preference for the subject relative

Table 1
The German article (in italics) and relative pronoun system

	Feminine	Masculine	Neuter
Singular			
Nominative	*die* Direktorin	*der* Direktor	*das* Direktorium
Genitive	*der* Direktorin	*des* Direktors	*des* Direktoriums
Dative	*der* Direktorin	*dem* Direktor	*dem* Direktorium
Accusative	*die* Direktorin	*den* Direktor	*das* Direktorium
Plural			
Nominative	*die* Direktorinnen	*die* Direktoren	*die* Direktorien
Genitive	*der* Direktorinnen	*der* Direktoren	*der* Direktorien
Dative	*den* Direktorinnen	*den* Direktoren	*den* Direktorien
Accusative	*die* Direktorinnen	*die* Direktoren	*die* Direktorien

Table 2
Examples of sentence types used in the experiment with literal English translation (the italic type indicates the point of disambiguation)

Case ambiguous
Late disambiguation (by number marking in auxiliary)
Subject first relative clause (SR)
(1a) Das ist die Direktorin, die die Sekretärinnen gesucht *hat*.
This is the director that the secretaries sought has.
(1b) Das sind die Sekretärinnen, die die Direktorin gesucht *haben*.
These are the secretaries that the director sought have.
Object first relative clause (OR)
(2a) Das ist die Direktorin, die die Sekretärinnen gesucht *haben*.
This is the director that the secretaries sought have.
(2b) Das sind die Sekretärinnen, die die Direktorin gesucht *hat*.
These are the secretaries that the director sought has.
Case unambiguous
Early disambiguation (by case marking in noun phrase)
Subject first relative clause (SR)
(3) Das sind die Sekretäre, die *den Direktor* gesucht haben.
These are the secretaries that the (ACC sg) director sought have.
Object first relative clause (OR)
(4) Das sind die Sekretäre, die *der Direktor* gesucht hat.
These are the secretaries that the (NOM sg) director sought has.
Immediate disambiguation (by case marking in pronoun)
Subject first relative clause (SR)
(5) Das ist der Direktor, *der* die Sekretäre gesucht hat.
This is the (NOM sg) director that (NOM sg) the secretaries sought has.
Object first, relative clause (OR)
(6) Das ist der Direktor, *den* die Sekretäre gesucht haben.
This is the (NOM sg) director that (ACC sg) the secretaries sought have.

structure and processes of reanalysis should be visible in on-line measures when encountering information disambiguating the sentence within an object relative structure. According to Frazier such a preference may not necessarily be visible in off-line measures. For the Capacity Constrained Model (MacDonald et al., 1992) the predictions for high and low span readers are as follows: In the behavioral off-line measures high and low span readers should display no performance differences for the processing of subject relative clause sentences irrespective of the point of disambiguation. However, for the processing of non-preferred object relative clause sentences low span readers should show more errors in question answering performance when the ambiguity region is long than when it is short because only one reading may be available late in the ambiguous region for these readers. If this is the case, then we would expect effects of reanalysis to appear on-line when disambiguation is sentence final. For the high span readers no such difference should be observable as both interpretations should be available throughout the sentence for these readers. If this is the case no effects of reanalysis should be found for high span readers.

The particular predictions for the ERP components registered in the present study are based on earlier ERP studies investigating the processing of garden-path sentences. Osterhout and colleagues (Osterhout and Holcomb, 1992, 1993; Osterhout et al., 1994) found higher processing costs in recovery from garden-path sentences in English to be correlated with a positive component around 600 ms. A study investigating the processing of subject (1) and object relative (2) clause sentences in German found higher cost in processing object versus subject relative clause sentences to correlate with the amplitude of a positivity present around 350 ms (Mecklinger et al., 1995)[1].

1. Das ist die *Professorin*, die die Studentinnen gesucht *hat* – This is the *professor* that the students sought *has*.
2. Das ist die Professorin, die die *Studentinnen* gesucht *haben* – This is the professor that the *students* sought *have*.

The positivity was interpreted to be correlated with processes of reanalysis that become necessary if the initial structure constructed during processing is a subject-first structure. This interpretation was based on the strong behavioral evidence of a subject-first preference in subject-object ambiguous structures (e.g., Frazier and Flores d'Arcais, 1989; De Vincenzi, 1991; Schriefers et al., 1995). This positive ERP component was only found for good comprehenders grouped post-hoc on the basis of the participant's performance on comprehension questions asked after each sentence. These performance measures correlated with the subjects' reading span. Thus, only good comprehenders, i.e. high span readers, showed a positivity in the ERPs at the disambiguating element indicating reanalysis. These data seem to suggest that only high span readers were led down the garden-path, that is, initially constructed only a subject-first structure. This pattern is clearly not compatible with the view that high span readers keep multiple representations active throughout the ambiguous part of the sentence. The processes underlying comprehension in the poor comprehenders (i.e. low span readers) were less easy to infer from this ERP study as they showed no effect at the disambiguating element. A possible interpretation of the absence of such an effect at the point of disambiguation could be that both representations were available to these subjects throughout the sentence. This interpretation, however, is weakened by the fact that low span readers' accuracy in the question answering task was below that of the high span readers.

An alternative interpretation proposed here for the ERP difference observed between the high span and the low span readers (Mecklinger et al., 1995) might be called the Early Commitment Model. This model makes assumptions contrary to the Capacity Constrained Model. In the Early Commitment Model so-called high span readers are assumed to be effective in parsing because they commit themselves to only one, namely the simplest syntactic structure compatible with the input, even

[1] This study, in contrast to the present study, only included temporarily ambiguous sentences disambiguated at the sentence final auxiliary. Recall that German, unlike English, is a verb-final language with respect to subordinate clauses.

though they risk being led down the garden-path. Low span readers, in contrast, try to hold multiple representations active and consequently show no on-line effect of disambiguation. Given the memory load required for holding multiple representations active, less capacity may be available for the final selection of the ultimate structure which in turn may lead to poorer comprehension performance. The assumption that high span readers but not low span readers take the risk of a reanalysis also explains why high span readers show longer reading times (reanalysis) than low span readers (no reanalysis) at the point of disambiguation. This view provides an alternative explanation to the one proposed by MacDonald et al. (1992). It allows one to turn 'the counterintuitive prediction that high span readers will show *more* effect of ambiguity than low span readers' (MacDonald et al., 1992, p. 59) into an intuitive prediction. High span readers show longer reading times because they have to recover from the initially built simple structure. It should be noted that the predictions formulated on the basis of the Capacity Constrained Model differ for syntactic and lexical ambiguities. Increased reading times for the ambiguity are taken to reflect the maintainance of multiple representations in the case of syntactic ambiguity (MacDonald et al., 1992), but are taken to reflect the commitment to only one, namely the subordinate word meaning in case of lexical ambiguity (Miyake et al., 1994).

Daneman and Carpenter (1980) consider the difference between high and low span readers to be due to the use of different chunking processes. Chunking of the incoming input and representation might be more 'efficient' in good readers who usually show a high memory span. We propose that the efficiency of syntactic processing may depend on a different aspect, namely the way in which readers make early commitments when processing ambiguous structures. Given the available evidence from previous behavioral and ERP studies on the processing of temporarily ambiguous structures and our assumptions about Early Commitment, we predict the following differences for high and low span readers in processing ambiguities: When ambiguous regions are long, high span readers should perform better than low span readers (cf. Mecklinger et al., 1995). If the hypothesis of early structural commitment in the case of high span readers is valid we should observe disambiguation effects on-line, that is at the earliest point of disambiguation and not later in the sentence. If structural commitments are not made early, as assumed in the case of low span readers, effects of disambiguation may not be present at the point of disambiguation.

The sentence material of the present study used case ambiguous and unambiguous sentences. As the case marked disambiguating element in the unambiguous sentences appeared in different positions (immediate and early disambiguation), it will be of interest to see whether this information will function as an equally efficient cue for structural reanalysis in these different sentence positions. Based on earlier ERP findings discussed above we consider the predicted processes of disambiguation and reanalysis to be reflected by a positive ERP component.

2. The present study

We chose to test the possible differential strategies in an experiment in which readers were presented with sentences of preferred subject-first (sentence type (1), (3), and (5) in Table 2) and non-preferred object-first clause structures (sentence type (2), (4), and (6) in Table 2). We varied the point at which unambiguous structural assignment was possible. Unambiguous assignment was either possible immediately, i.e. at the beginning of the clause due to unambiguous case marking of the pronoun (sentence type (5) and (6) in Table 2), early in the clause due to unambiguous case marking in the noun phrase following the case ambiguous pronoun (sentence type (3) and (4)) or late in the clause (sentence type (1) and (2) in Table 2) due to number marking in the sentence final auxiliary that agreed in number with the subject.

3. Methods

3.1. Participants

Twenty students (12 females) of the Free University of Berlin participated as paid volunteers. Their mean age was 25.9 years (range 21–30 years). All were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). They were all native German speakers with normal or corrected-to-normal vision. Prior to the ERP experiment, participants were tested for their sentence memory span with a German version of the Daneman and Carpenter (1980) Reading Span test. On the basis of their performance in this test, ten participants (7 female) with a mean age of 24.9 years (range 21–30) were assigned to a low span group (≤ 3.5; mean span 3.25, range 2.5–3.5) and ten participants (5 female) with a mean age of 26.4 years (range 23–30) were assigned to a High Span group (≥ 4; mean span 4.65, range 4.0–6.0). Each subject participated in two experimental sessions which were separated by an interval of about one week.

3.2. Materials

A total of 256 sentences were constructed. Half of the sentences contained an *ambiguously case marked* relative pronoun (feminine) and were disambiguated by number marking the sentence final verb (late disambiguation). The remaining sentences were *unambiguously case marked* either by a marked relative pronoun (masculine) in clause initial position (immediate disambiguation) or by case marking the noun phrase following the relative pronoun (early disambiguation). In each of these sets, sentences belonged to 2 different structural categories: Subject relative clause sentences and object relative clause sentences (for examples see Table 2). There were 32 NP-NP-Verb combinations that were used to construct the experimental sentences (see Appendix A). Note that all verbs were transitive verbs requiring a direct accusative object. Nouns were chosen in such a way that neither

of the two nouns within one sentence was more likely to be the agent of the action, given the verb. Each noun appeared equally often in subject and object position. In half of the sentences the first noun was marked plural and the second singular, and in half of the sentences vice versa. From each of the 32 NP-NP-Verb combinations eight relative clause sentences were derived, four of which were disambiguated at the sentence final auxiliary and four prior to it either by case marking the pronoun or the noun phrase[2].

Prior to the experiment the sentence material was tested for grammatical acceptability. In this test, ambiguously and unambiguously case marked sentences were presented in a mixed order. The unambiguously case marked sentences contained two case marked noun phrases each. Twenty-one native German speakers, students of the Free University of Berlin, participated in the test. For the subject first relative clause sentence the percentage of grammatical acceptability was 88% for the case ambiguous and 92% for the case unambiguous sentences; for the object first relative clause sentences it was 70% for the case ambiguous and 93% for the case unambiguous sentences. An ANOVA with factors case marking (ambiguous vs unambiguous) and sentence structure (subject vs object relative) revealed main effects of both case marking ($F(1,20) = 25.86$; $P < 0.0001$) and structure ($F(1,20) = 10.80$; $P < 0.005$) as well as a significant interaction ($F(1,20) = 15.37$; $P < 0.001$). The difference in acceptability between subject and object relative clauses was significant for case ambiguous ($F(1,20) = 15.76$; $P < 0.001$) but not for morphologically case marked sentences ($F < 1$).

3.3. Procedure

The participants were seated comfortably in a dimly lit room in front of a VGA monitor. The sentences were displayed in six chunks of either one or two words.

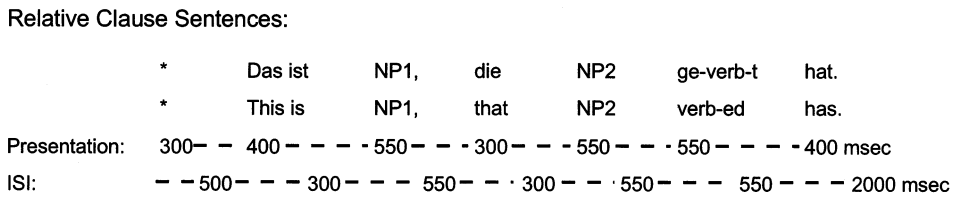


Fig. 1. Temporal scheme of sentence presentation. Presentation chunks and interstimulus interval (ISI) between chunks are displayed in milliseconds.

[2] The high constraints on the material, i.e. (a) semantically neutral verbs with respect to a possible interpretation of the relation between the two noun phrases (*director*, *secretary*, *to see* vs *director secretary*, *to fire*) and (b) unprefixed verbs as in German the past participle marker *ge-* appears in word initial position for unprefixed verbs (*ge-sehen*/*seen*) but not for prefixed verbs (*an-ge-sehen*/*looked at*) reduced the number of possible sentences usuable as stimulus material. Due to these constraints sentences were repeated across the different conditions. Potential repetition effects, however, are constant for all conditions as these were carefully counterbalanced across the experiment.

Each trial started with the presentation of a fixation cross in the center of the screen for 300 ms. After this, the stimulus sentences were presented according to the presentation scheme displayed in Fig. 1.

Two seconds after sentence offset, a question concerning the content of the preceding sentence was presented until the participant responded with a button press ('yes' vs 'no') or until 2 s had elapsed. This question always had the form 'Was NP1/NP2 verb-ed?'. Each response was immediately followed by a feedback stimulus (600 ms) that informed the subjects about the accuracy of the response (correct/incorrect). The next trial began 1700 ms later, with the presentation of the fixation cross. A 2-s interval between the offset of the auxiliary and the onset of the question was selected to give the subject enough time to prepare for the comprehension question.

The words were presented in black letters against a light gray background in the center of a 17''-computer screen. Proportional fonts were used, with a letter height of 1 cm. The use of lower- and uppercase letters conformed to the rules of German orthography. The participants sat at a distance of 70–80 cm from the screen. They used the two mouse keys to respond either 'yes' or 'no' to the question. Response key assignments were counterbalanced across participants. The participants were instructed to respond as quickly and as accurately as possible and were informed of the importance of avoiding large body movements. They were told that they could blink their eyes during the time interval between the response and the onset of the fixation cross of the next trial. Each participant performed a practice sequence of 24 trials. The 256 experimental sentences were presented together with 256 sentences containing subject-first and object-first complement clauses used as filler items[3]. All 512 sentences were distributed over 8 blocks. Each block contained 64 sentences randomized according to a Latin square. Thus, each block contained four sentences from each of the 8 conditions. Blocks 1 to 4 were assigned to the first and blocks 5 to 8 to the second experimental session. Those sentences that appeared in their ambiguous case marked form in session one appeared in their unambiguous case marked form in session two and vice versa. The blocks lasted about 12 min and were separated by a short break. Each session, including electrode application and removal, lasted about 2 h.

3.4. EEG recording

The EEG activity was recorded by means of 11 tin electrodes mounted in an elastic cap (Electro-Cap International). The scalp sites included seven locations based on the International 10–20 System: (Fz, Cz, Pz, F3, F4, O1, O2). Recordings were also taken from four nonstandard locations, including the Wernicke area (hereafter, WL), and its right hemisphere homologue (hereafter, WR). WL was defined as the crossing point between T5-C3 and T3-P3 (WR, between T6-C4 and

[3] See Friederici, 1997. In this paper only high span participants' results for relative and complement clauses are discussed as low span participants' error rate for complement clauses was too high to allow an adequate ERP analysis.

T4-P4). Two electrodes were positioned over the Broca area (hereafter, BL) and its right hemisphere homologue (hereafter, BR). BL was defined as the crossing point between T3-Fz and F7-Cz (BR, between T4-Fz and F8-Cz). All electrodes were referenced to left mastoid. The ground electrode was positioned 10% of the nasion-inion distance posterior to Fz. The vertical EOG was monitored with two electrodes located above and below the participant's right eye. The horizontal EOG was recorded from electrodes placed at the outer canthus of each eye. Electrode impedances were kept below 5 kΩ. The EEG and EOG electrodes were amplified by Neuroscan amplifiers (DC to 30 Hz). The EEG and EOG were recorded continuously for each block of trials and were A/D converted with 16-bit resolution at a rate of 250 Hz. Data collection was controlled by an IBM-compatible 486 computer.

3.5. Data analysis

3.5.1. Behavioral data

Answers to the questions following each sentence were scored with respect to their accuracy.

3.5.2. ERP data

ERPs were calculated for each subject at various sentence positions in each of the experimental conditions: First, ERPs were computed for the *sentence final auxiliary* from 200 ms prior to the auxiliary until 900 ms thereafter. Second, ERPs were also examined for the *clause initial relative pronoun*. Third, ERPs were computed for the *noun phrase* following the pronoun. For the within sentence ERPs the time epoch for ERP averaging extended from 200 ms prior to the relative pronoun until 900 ms (relative pronoun) or 1200 ms (noun phrase) thereafter.

Only sentences for which the question was answered correctly were included in the ERP averages. Epochs containing ocular artifacts (criterion ± 50 μV) or other movement artifacts were excluded from further analyses. On the basis of this procedure, approximately 13% of all trials had to be rejected. The proportion of rejected trials did not differ between the experimental conditions within each group. Prior to the estimation of the ERP components, the subject averages were digitally filtered with a phase-true digital low-pass filter (-3 dB at 10 Hz, -45 dB at 23 Hz). ERP components were quantified as the mean voltage within particular time periods following either the auxiliary, the relative pronoun, or the first noun phrase in the embedded clauses. The latency windows used to quantify the ERP responses to the auxiliary were 300 to 400 ms and 600 to 900 ms. These windows were selected on the basis of previous studies demonstrating early and late positivities to syntactic anomalies (Osterhout and Holcomb, 1992, 1993; Mecklinger et al., 1995). Similar time windows were chosen for the disambiguating pronouns as we expected positivities as a reflection of the revision process for these elements as well. For the noun phrase a different time window was chosen due to the fact that the critical condition (object relative) showed a more negative going wave form compared to the subject relative condition. For this comparison we chose the time window between 400 and 600 ms in order to test for a possible N400 effect.

Table 3
Accuracy of question answering performance (% correct) as a function of point of disambiguation and clause structure in both the high and the low span groups

Clause structure	High span	Low span
	% Correct (SD)	% Correct (SD)
Case ambiguous: Late disambiguation by number marking		
Subject first	90.8 (7.2)	82.2 (9.3)
Object first	91.6 (4.3)	83.9 (5.4)
Case unambiguous: Early disambiguation by case marking		
Subject first	96.2 (2.9)	94.4 (4.4)
Object first	95.6 (4.2)	92.8 (67.3)
Case unambiguous: Immediate disambiguation by case marking		
Subject first	95.6 (5.5)	90.6 (6.7)
Object first	92.5 (8.2)	91.6 (7.4)

An overall ANOVA design with factors structure (subject-first vs object-first), time window (2 levels, see above) and electrode (11 sites) was performed for the ERPs to the clause initial relative pronoun, the noun phrase following the pronoun and the sentence final auxiliary for the high and low span group. In cases of significant interactions involving clause type or time window ANOVAs were performed separately for each clause type and time window. All within-subjects main effects or interactions with two or more degrees of freedom in the numerator were adjusted with the procedure suggested by Huynh and Feldt (1970).

4. Results

4.1. Behavioral data

Table 3 presents mean performance accuracy in each of the experimental conditions.

As apparent from Table 3 high span readers responded more accurately to the question following the sentence than low span readers. There was no advantage for the preferred subject-first over the object-first sentences in either group.

An overall ANOVA for the error data with the factors group × structure × case marking revealed a main effect of group ($F(1,18) = 7.00$, $P < 0.05$) with more errors for the low span readers than for the high span readers, a main effect of case marking ($F(1,18) = 31.14$, $P < 0.001$) with more errors for the sentences with case ambiguous NPs, and a main effect of number ($F(1,18) = 7.22$, $P < 0.05$) indicating more errors for the sentences in which singular NPs preceded the plural NP compared to those sentences with the reverse NP order. There was also a group × case marking interaction ($F(1,18) = 5.41$, $P < 0.05$) due to the case marking effect being stronger for the low span readers than for the high span readers.

When calculating separate ANOVAs for case marked and case ambiguous sentences we found no main effect of group for the case marked sentences ($P > 0.1$), but a main effect of group was found for the case ambiguous sentences ($F(1,18) = 8.64$, $P < 0.01$), reflecting more errors for the low span readers than for the high span readers. In the analysis for case marked sentences there was also a main effect of number ($F(1,18) = 7.67$, $P < 0.05$) indicating more errors for the immediate disambiguation condition (unambiguous singular pronoun preceding ambiguous plural NP) than for the early disambiguation condition (ambiguous plural pronoun preceding unambiguous singular NP). Thus high and low span readers appear to have more difficulties processing the case ambiguous sentences (late disambiguation) than those containing case marked elements (immediate and early disambiguation). Error scores suggest that low span readers, in particular, are impaired in processing sentences which are disambiguated by number in the sentence final position, i.e. sentences with long ambiguous regions (late disambiguation).

In addition to these ANOVAs, correlational analyses between the performance data and the individual reading span scores were carried out. Significant correlations were found between the reading span and the error scores, however, only for the ambiguous sentences and, in particular, for the object relative sentences (object relative: $r = -0.687$, $P < 0.001$; subject relative: $r = -0.457$, $P < 0.05$).

4.2. Event-related potentials

Separate ANOVAs were carried out for the case ambiguous (late disambiguation) and the two case marked constructions either disambiguated at the relative pronoun (immediate disambiguation) or the noun phrase following the relative pronoun (early disambiguation). Separate ANOVAs for each disambiguation condition were carried out because targets in the early, immediate, and late conditions are members of different word categories (auxiliary, pronoun and noun phrase) and because the immediate but not the early and late disambiguation condition includes the factor 'number'. We will first consider case ambiguous sentences which were disambiguated at the sentence final auxiliary.

5. Case ambiguous sentences: late disambiguation

5.1. Sentence final auxiliary

For the sentence final auxiliary in the case ambiguous condition we observed a centro-parietal positivity for the object compared to the subject relative sentences in the high span group, but not in the low span group. Fig. 2A shows the grand average ERPs in the interval from the onset of the sentence final auxiliary for the case ambiguous relative clause sentences for the high span group and Fig. 2B for the low span group. In this and the following figures the ERPs from subject-first (solid lines) and object-first sentences (dotted lines) are superimposed. For the high span group the ERPs at all electrodes were similar for the first 200 ms. Between 300

and 400 ms after the onset of the auxiliary we observed an early positivity most pronounced at the three midline electrodes Fz, Cz and Pz and a second less pronounced positivity between 600 and 900 ms. Both components were larger for the object relative clauses than for the subject relative clauses.

For the low span group we observed no such positivity at the sentence final auxiliary. An ANOVA for this sentence final auxiliary in the case ambiguous sentences with the factors group (high vs low) × structure (subject relative vs object relative) × time window (early = 300–400 ms vs late = 600–900 ms) × electrode (11) revealed a main effect of structure ($F(1,18) = 6.99$, $P < 0.02$), a main effect of time window ($F(1,18) = 6.92$, $P < 0.02$), a group × structure interaction ($F(1,18) = 10.74$, $P < 0.005$) and a structure × time window × electrode interaction ($F(10,180) = 3.06$, $P < 0.04$). Separate ANOVAs for each group were calculated to evaluate the group

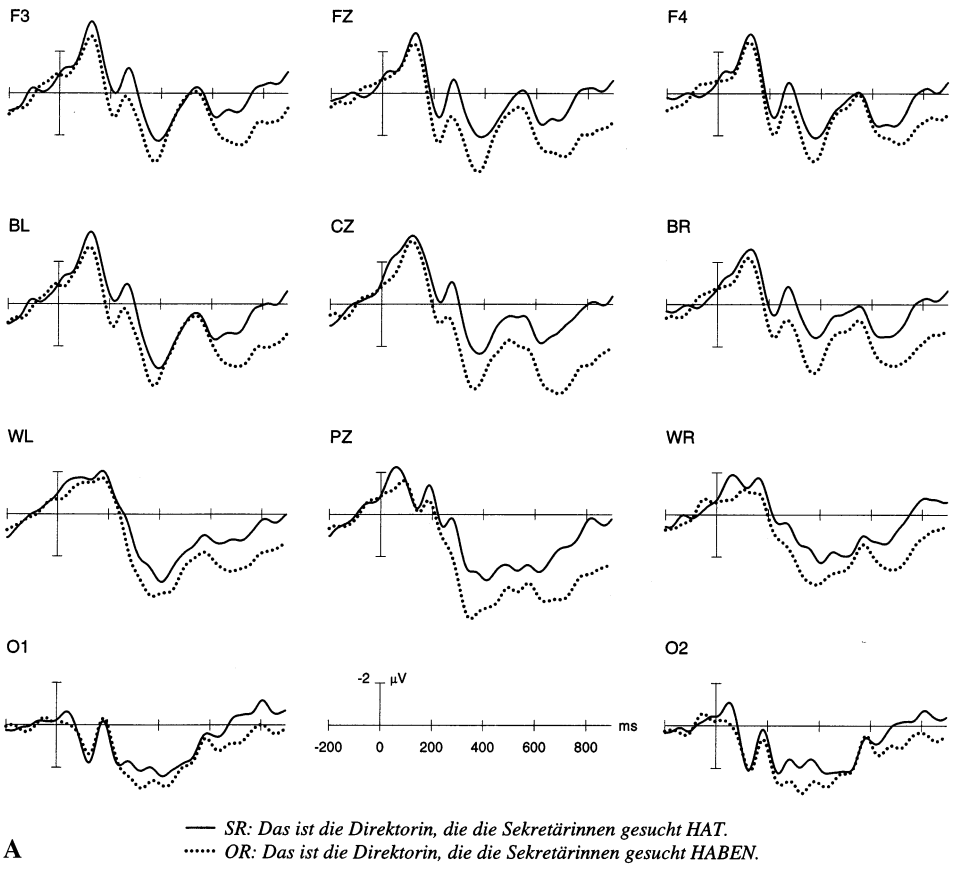
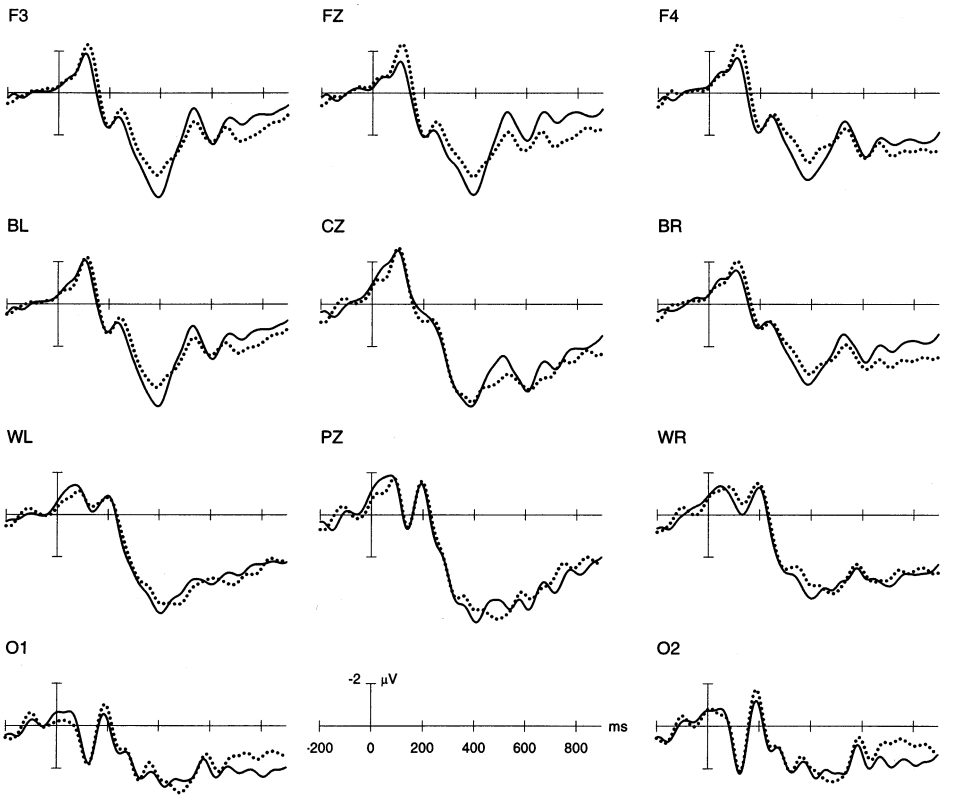


Fig. 2. Grand average ERPs elicited by the sentence final auxiliary for high span (A) and low span readers (B) in the case ambiguous – late disambiguation condition. The wave forms are superimposed for subject and object relative sentences. The vertical lines indicate the onset of the auxiliary.



B

—— *SR: Das ist die Direktorin, die die Sekretärinnen gesucht HAT.*
····· *OR: Das ist die Direktorin, die die Sekretärinnen gesucht HABEN.*

Fig. 2. (*Continued*)

by structure interaction. High span readers showed a main effect of structure ($F(1,9) = 22.58,\ P < 0.002$) with larger positive amplitudes for the object relative than for the subject relative sentences, and a main effect of time window ($F(1,9) = 5.17,\ P < 0.05$). Separate analyses for the different time windows showed a significant effect of structure for the early time window ($F(1,9) = 11.55,\ P < 0.01$) and for the late time window ($F(1,9) = 11.72,\ P < 0.01$) with larger amplitudes for the object relative than for the subject relative clause sentences. For the low span readers no significant effect of structure was found in an ANOVA with the factors structure × time window × electrode. It could also be argued that, rather than reflecting two distinctive positivities evoked by OR-sentences, there is one large positivity that is interrupted by an N400 in the object-relative condition for the high span readers (cf Fig. 2A). To examine this issue we conducted a peak-to-peak analysis. The peak-to-peak distance between the early positivity and the assumed subsequent negativity at the CZ recording was 3.1 μV in the SR condition and 3.6 μV in the OR condition. As revealed by a t-test for dependent variables, this

difference was not significant, $P > 0.16$. This result makes the view that the OR relative sentences generate an N400 rather unlikely.

The view that two distinct positivities were elicited by the object relative clauses at the sentence final position for the high span group was confirmed by additional statistical analyses performed for successive time intervals of 50 ms duration. More positive going wave forms for object relative than for subject relative clauses were obtained between 300 ms and 400 ms (P's < 0.05) and between 650 ms and 900 ms (P's < 0.01) whereas no such differences were obtained in the time intervals from 400 to 650 ms (P's > 0.25).

For the low span group only a significant three-way interaction ($F(10,90) = 5.7$, $P < 0.01$) was obtained. Additional separate analyses for each time window showed that this interaction was due to an electrode × structure interaction in the late time window ($F(10,90) = 3.77$, $P < 0.01$). To further analyze this interaction two additional analyses were computed:

1. the effect of structure was tested for each electrode and
2. the effect of electrode was tested separately for subject relative and object relative clauses.

The effect of structure did not reach significance at any of the eleven electrodes. The effect of electrode was significant for the object relative clauses ($F(10,90) = 3.08$, $P < 0.05$), but not for the subject relative clauses ($P > 0.1$). Thus, the interaction does not reflect a local effect of structure, but rather a larger variability across electrodes in the object relative clause condition.

The positive component which shows a larger amplitude for the non-preferred object relative clauses than for the preferred subject relative clauses observed for the high span readers can be interpreted with respect to earlier findings. Mecklinger et al. (1995), using similar sentences, found a positivity around 350 ms for the sentence final disambiguating auxiliary in case ambiguous relative clause sentences for good comprehenders, i.e. subjects with fast question answering times to questions concerning the thematic relations of the relative clauses. This positivity was taken to reflect the assumed reanalysis which becomes necessary with an initial preference for a subject-first structure at the point where unambiguous number marking indicates an object-first structure. The positivity observed in the present study showed two peaks, one around 350 ms and a second one between 600 and 900 ms. We consider the difference between these two studies to be due to the fact that the earlier study only included case ambiguous subject-object relative clause sentences which were always disambiguated at the sentence final auxiliary whereas in the present study case ambiguous sentences only made up half of the experimental material. The first positivity may therefore reflect a fast detection of a structure which is deviant from the initial structure and requires reanalysis, present in both studies, whereas the second positivity may reflect a secondary check for structural adequacy more likely to occur under an experimental setting including not only case ambiguous subject relative and object relative sentences but also other sentence types only.

The absence of a similar difference between the two conditions in the low span group seems to suggest that low span readers are not engaged in revision processes

when reading clause final disambiguating information. If the difference between subject and object relative clauses reflects processes of reanalysis the most straightforward interpretation of its absence would be that low span readers keep the two possible structures active. Another possible interpretation of the finding that low span readers do not show any differences between the preferred and the non-preferred structure, however, would be that both types of structures are equally hard to process for low span readers. These possible interpretations are discussed in more detail in Section 7 – Discussion.

6. Case unambiguous sentences: immediate and early disambiguation

In the case marked sentences disambiguation is possible either at the pronoun, i.e. immediately or at the NP following the pronoun, i.e. early in the sentences. As disambiguation in these sentences is possible prior to the auxiliary no effect should be found in these sentences for this element.

6.1. Sentence final auxiliary

In the immediate disambiguation condition, we did not find effects of sentence structure at the sentence final auxiliary for high span or low span subjects. However, both groups showed a larger centro-parietal positivity for object relative clauses in the early disambiguation condition. An ANOVA for the auxiliary condition included the factors group × structure × number × time window × electrode. The factor number was included in this analysis to separate immediate disambiguation (singular pronoun in sentence type (5) and (6)) and early disambiguation (plural pronoun in sentence type (3) and (4); cf. Table 2). This analysis did not reveal significant main effects of either group or structure. There were significant main effects of time window ($F(1,18) = 60.0$, $P < 0.0001$) and electrode ($F(10,180) = 7.62$, $P < 0.0001$). Interestingly, significant structure × number ($F(1,18) = 6.08$, $P < 0.03$) and structure × number × time window interactions ($F(1,18) = 7.67$, $P < 0.02$) were obtained.

In order to evaluate these interactions separate analyses were carried out for the immediate disambiguation (singular pronoun) and the early disambiguation (plural pronoun) conditions with the factors group × structure × time window × electrode. As expected, sentences which were disambiguated immediately, i.e. at the relative pronoun, did not show a significant main effect of structure at the auxiliary ($P > 0.1$). There was only a significant main effect of time window ($F(1,18) = 40.68$, $P < 0.0001$). Sentences which were disambiguated early, i.e. at the noun phrase following the pronoun similarly revealed a main effect of time window ($F(1,18) = 58.14$, $P < 0.0001$). Moreover, there was also a main effect of structure ($F(1,18) = 6.33$, $P < 0.03$), indicating a more positive going wave at the sentence final auxiliary for the object relative than for the subject relative clause sentences. The structure × time window interaction was significant ($F(1,19) = 8.05$, $P < 0.02$) and reflected that the positivity for the object relatives was present in the early time window but not

in the late time window. This pattern was observed for both the high span ($F(1,9) = 4.92$, $P < 0.053$) and low span readers ($F(1,9) = 5.49$, $P < 0.044$).

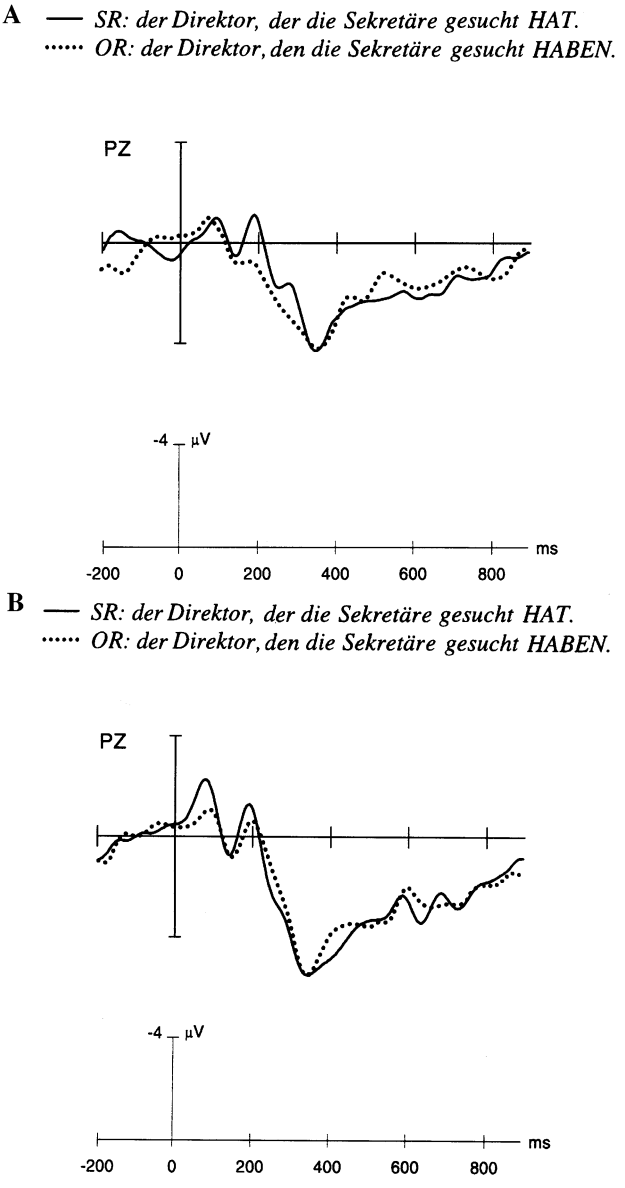


Fig. 3. Grand average ERPs elicited by the sentence final auxiliary for high span (A) and low span readers (B) in the case marked – immediate disambiguation condition. The wave forms are superimposed for subject and object relative sentences. The vertical lines indicate the onset of the auxiliary.

The ERPs for the sentence final auxiliary in the immediate disambiguation condition are shown in Fig. 3. Fig. 3A displays the ERPs evoked by subject and object relative clause for the high span group. The corresponding effects for the low span group are shown in Fig. 3B. As apparent from the figure, no systematic differences between the two relative clause conditions were obtained in either group.

The effect found for the early disambiguation condition is shown in Fig. 4. Fig. 4A displays the grand average ERPs evoked by the clause final auxiliary in the early disambiguation condition for the high span group and Fig. 4B for the low span group.

This effect at the auxiliary in the early disambiguation condition was unexpected because the correct structure could have been assigned before the auxiliary on the basis of the case marking information carried by the article in the noun phrase following the clause initial relative pronoun. Thus, although both the immediate and the early disambiguation allow structural disambiguation prior to the auxiliary, readers showed a positivity at the auxiliary in the early disambiguation condition, but not in the immediate disambiguation condition. This seems to suggest that readers use the case marking information for immediate structural assignment when carried by the clause initial relative pronoun, but not when carried by the noun phrase in clause medial position. We will discuss this difference in more detail in Section 7 – Discussion.

6.2. Case marked elements

Contrary to the finding for the sentence final auxiliary, the a priori prediction for the case marked sentences was that particular effects should *only* be present at the disambiguating element, namely the case marked relative pronoun and the case marked noun phrase. In the following section we will first present the data on the clause initial case marked relative pronoun (immediate disambiguation) and then on the case marked noun phrase (early disambiguation).

6.2.1. Case marked relative pronoun: immediate disambiguation

Fig. 5A displays the grand averages of the ERPs in the interval from the onset of the disambiguating clause initial pronoun for the high span group and Fig. 5B for the low span group. For both groups, the ERPs for both sentence types are of a similar form during the first 250 ms. ERPs after 300 ms with the unambiguously case marked object relative clause sentence displayed a larger positive component most pronounced between 500 and 900 ms for the high span group and between 500 and 700 ms for the low span group.

An ANOVA for the relative pronoun with the factors group × structure × number × time window × electrode revealed no main effect of group ($P > 0.1$), but a group × number interaction ($F(1,18) = 5.85$, $P < 0.03$), a number × time window interaction ($F(1,18) = 5.89$, $P < 0.03$), a structure × time window interaction ($F(1,18) = 14.3$, $P < 0.002$), a marginally significant number × structure interaction ($F(1,18) = 3.78$, $P < 0.07$) and a structure × electrode interaction ($F(10,180) = 2.43$,

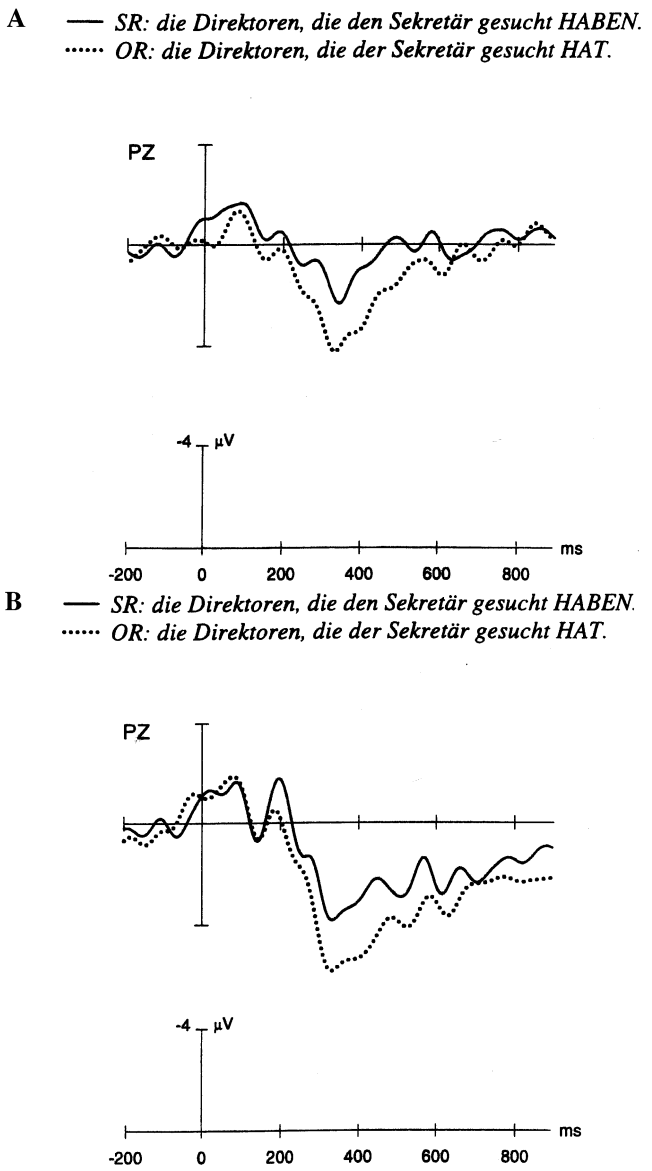


Fig. 4. Grand average ERPs elicited by the sentence final auxiliary for high span (A) and low span readers (B) in the case marked – early disambiguation condition. The wave forms are superimposed for subject and object relative sentences. The vertical lines indicate the onset of the auxiliary.

$P < 0.04$). These interactions were examined in further analyses. Separate ANOVAs for high and low span subjects revealed a main effect of number for high span readers ($F(1,9) = 7.60$, $P < 0.02$), but not for low span readers. An ANOVA for the singular forms with the factors group × structure × time window × electrode

showed a main effect of structure ($F(1,18) = 5.01$, $P < 0.04$) and a structure × time window interaction ($F(1,18) = 15.8$, $P < 0.001$) reflecting the finding that there was a late positivity, but no early positivity. This interaction was significant in both the

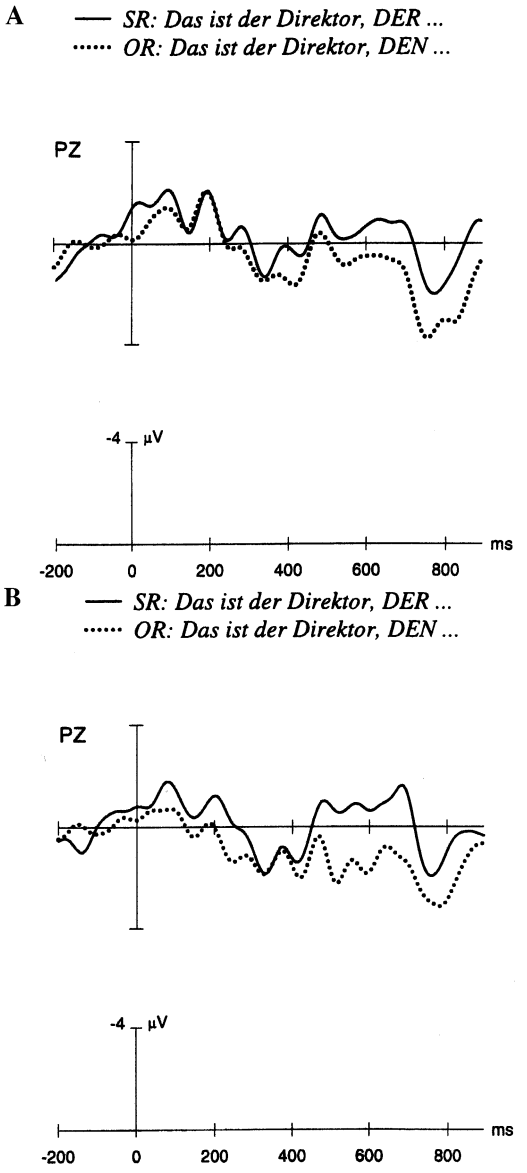


Fig. 5. Grand average ERPs elicited by the case marked relative pronoun for high span (A) and low span (B) readers in the immediate disambiguation condition. The wave forms are superimposed for subject and object relative sentences. The vertical lines indicate the onset of the relative pronoun.

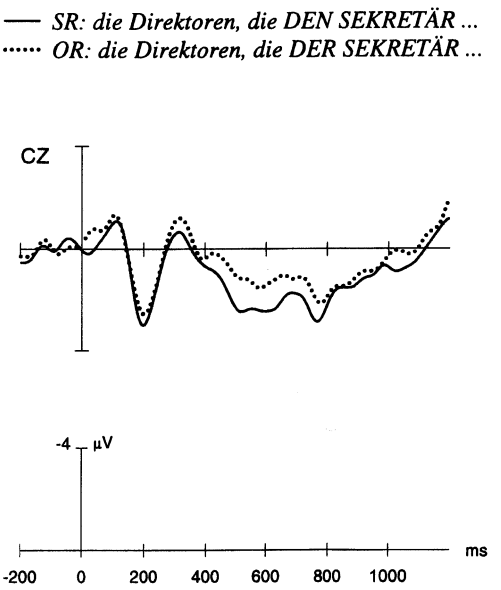


Fig. 6. Grand average ERPs, averaged across high span and low span readers, elicited by the case marked noun phrase (*der NOUN*) following the ambiguous pronoun. The wave forms are superimposed for subject and object relative sentences. The vertical lines indicate the onset of the noun phrase.

high span ($P < 0.02$) and the low span group ($P < 0.02$). Thus, as expected we observed a positivity, i.e. a more positive going wave for the non-preferred compared to the preferred structure, at the element disambiguating the clause immediately.

6.2.2. Case marked noun phrase: early disambiguation

For the disambiguating noun phrase, ANOVAs were only carried out for the singular NPs (masculine versus feminine) as the plural NPs were preceded by the disambiguating relative pronoun eliciting a P600 effect which fell into the baseline for the plural relative pronoun.

Visual inspection of the wave forms (see Fig. 6) suggested a more negative going wave between 400 and 600 ms for the object relative sentences than for the subject relative sentences for both groups. An ANOVA for the time window 400–600 ms with the factors group × structure × electrode was carried out. This analysis showed a main effect of structure ($F(1,18) = 5.28$, $P < 0.04$). This finding was not predicted, but we will provide a post hoc interpretation for it in Section 7, which considers the interaction for the form ambiguity of the case marking element (*der*) and its position in the sentence.

7. Discussion

Parsing strategies for temporarily ambiguous and unambiguous sentences were explored in high and low span readers using off-line behavioral as well as on-line ERP measurements. The off-line measures and the ERP data showed a number of similarities between the two groups, but also interesting differences.

7.1. Off-line behavioral data

Both groups answered the questions equally well when the preceding sentence was disambiguated immediately or early by case marking information. When the preceding sentence included a long lasting ambiguity, low span readers made more errors than high span readers. The behavioral measures gave no indication that subject relative clause sentences are easier to process than object relative clause sentences either by high span readers or by low span readers.

7.2. On-line ERP-data

7.2.1. Late disambiguation by number marking

The ERPs revealed differential forms for the high and the low span readers dependent on the sentence type. For sentences in which disambiguation occurred at sentence final positions (late disambiguation) we found a positivity between 300 and 400 ms followed by a second positivity between 600 and 900 ms for the object as compared to the subject relative sentences for the high span readers, but not for the low span readers. The larger positivities for the object compared to the subject relative sentences for the high span readers are partly compatible with earlier findings which take the positivity as a possible indicator for revision processes (Mecklinger et al., 1995; Friederici, 1997) or processing costs (Osterhout and Holcomb, 1992) necessary to recover from a garden-path. In this context the presence of the positivity would imply either that high span readers initially constructed only one structure, namely the subject relative structure, which they have to revise when encountering the disambiguating information at the sentence final position. The data, however, are also compatible with the view that a second structure may have been considered initially but was no longer available at the end of the sentence.

The absence of a difference between the processing of the subject relative clause and the object relative clause for the low span group may be interpreted in two ways: If the positivity observed in correlation with processing garden-path sentences reflects processes of reanalysis we have to conclude that low span readers do not get involved in revision processes upon encountering the sentence final disambiguating element. This in turn would mean that both readings of the temporary ambiguity are available to them. The other possible interpretation is based on the assumption that the positivity reflects processing costs in general. Under this view the absence of the positivity for the non-preferred structure would be explained by the assumption that both structures, i.e. the subject relative clause and the object relative

clause, are equally easy or equally hard to process for low span readers. These interpretations may not be mutually exclusive. Under the assumption that low span readers keep both possible readings of a temporarily ambiguous structure active, both structures are equally hard to process.

A visual inspection of the wave forms elicited by the subject relative structure and the object relative structure for the low span readers seems to suggest that the absence of a difference is due to a positive shift in both conditions. A visual comparison of the wave forms of the low span readers with those of the high span readers indicates that the wave forms of both subject and object relative clauses for the low span readers resemble the positivity in amplitude for the object relative clauses in the high span readers. Thus, the positive going wave for the low span readers in both the subject and object relative condition raises the possibility that there are high processing costs for low span readers in both the subject and object relative clause conditions. Processing costs may be high for both sentences types as low span readers, once confronted with structural ambiguities, do not commit themselves to a preferred structure for the sentence and thereby to any particular structural relationships between phrases. Rather, the relationship between the phrases they construct on-line may remain open until disambiguating number information is encountered. Upon encountering this type of information, the relationship between the phrases will finally be established for subject as well as for object relative clauses by additional structural processes (evoking a positive going wave for both conditions).

7.2.2. Immediate and early disambiguation by case marking

When the sentence was completely unambiguous, i.e. in the immediate disambiguation condition, as expected, no difference was found at the sentence final auxiliary. Instead, for both high and low span readers we observed a late centro-parietal positivity between 600 and 900 ms at the disambiguating case marked pronoun indicating the structure of the clause. The ERPs were more positive for the accusative marked pronoun indicating an object relative clause than for the nominative marked pronoun indicating a subject relative clause. As the case marking in the pronoun makes the sentence unambiguous no reanalysis in the proper sense is required. Thus, the observed positivity should rather be interpreted as a reflection of a violation of a structural expectancy.

An interesting, but less clear case is the early disambiguation condition. In these sentences the reader is in principle able to disambiguate the sentence at the case marked noun phrase. If the reader would use the case marking information for disambiguation, no effect should be observed at the sentence final auxiliary. However, both high and low span readers showed a centro-parietal positivity between 300 and 600 ms post onset of the auxiliary. As similar positivities have been taken to reflect processes of reanalysis (Mecklinger et al., 1995; Friederici, 1997) the present positivity suggests that readers did not use the case marking information available in the NP for ultimate structural assignment. In the presence of a positivity at the sentence final auxiliary, it may not be surprising that no clear reanalysis effect was found at the disambiguating noun phrase earlier in the sentence.

It seems that both groups detect the case marking as indicated by a difference between the wave forms for the nominative and the accusative marked noun phrases, but that they do not use it for ultimate structural assignment. The observed difference at the noun phrase is a more negative going wave form for the nominative marked noun phrase (*der*) compared to the accusative marked noun phrase (*den*). To explain this effect we will consider the form-ambiguity of the case marked article '*der*' (see Table 1) and its possible interaction with this element's position in the sentence (clause initial vs clause second). It could either be nominative masculine, or dative or genitive feminine. Thus the article '*der*' as such does not necessarily require reanalysis as it could be read as a dative marker as in sentence (7).

(7)	*Das*	*sind*	*die*	*Sekretäre*,		
	These	*are*	*the*	*secretaries*,		
	die	*der*	*Direktorin*	*den Film*	*gezeigt*	*haben.*
	that	*the (DAT sg, fem)*	*director (fem)*	*the film*	*shown*	*have.*

The necessity for a reanalysis in sentences like (4) only becomes obvious when accessing the noun's gender, i.e. Direktorin (fem) vs Direktor (masc).

(4)	*Das*	*sind*	*die*	*Sekretäre*,	
	These	*are*	*the*	*secretaries*,	
	die	*der*	*Direktor*	*gesucht*	*hat.*
	that	*the (NOM sg, masc)*	*director (masc)*	*sought*	*has.*

Thus the more negative going wave form, which we observed may reflect aspects of lexical processing such as retrieving the gender of the noun. Due to structural preferences (subject-first) a masculine noun (signaling object-first) may be difficult to integrate. Interestingly, accessing gender information in sentence (4), although effecting processing, does not seem to lead to a structural reanalysis. Reanalysis appears to be postponed until number information is available at the sentence final auxiliary. Note that a similar situation is not given when the element '*der*' is used in clause initial position as a relative pronoun since a feminine (dative marked) relative pronoun cannot refer to a preceding noun phrase in the matrix clause which is marked for masculine gender (singular). Thus the particular effect observed for the second noun phrase of the relative clause in sentences like (4) may be due to the form-ambiguity of the article '*der*' (dative singular feminine vs nominative singular masculine) which can be resolved only after accessing the gender of the subsequent noun.

The general pattern observed for high span readers suggests a preference for subject relative clause sentences over object relative clause sentences. This is

indicated by the positivity observed for object relative clause sentences (a) at the case marked clause initial pronoun in the immediate disambiguation condition and (b) at the number marked clause final auxiliary in the late disambiguation condition. In the former case this positivity may reflect a violation of a structural expectancy for a subject-first structure and in the latter case a violation of an initially computed subject-first structure and the resulting reanalysis.

A comparison between high and low span readers demonstrates that low span readers basically show a similar ERP pattern in two of the three sentence conditions, namely in the immediate disambiguation condition and the early disambiguation condition. In the immediate disambiguation condition low span and high span readers displayed a late positivity at the case marked pronoun for the object relative sentences. This effect was taken to reflect a violation of the preferred and expected subject-first structure. In the early disambiguation condition both groups showed a similar positivity only at the sentence final number marked auxiliary, but not at the case marked noun phrase. At the noun phrase itself a more negative going wave was observed. This effect was explained to be due to the form-ambiguity of the article '*der*' (nominative singular masculine vs dative singular feminine) resolvable only after accessing the following noun's gender. A comparison between the immediate and the early disambiguation conditions suggest that case marking information is only used for ultimate structural assignment when highly reliable. This is true for the immediate disambiguation condition since the relative pronoun itself has to agree in gender with the preceding noun phrase of the matrix clause to which it refers. As the respective noun phrase of the matrix clause in (5) is masculine the relative pronoun *'der'* unambiguously marks for masculine nominative case (cf. Table 1). Initial form-ambiguity, however, comes to bear in sentences like (4) in which the case marked article of the second noun phrase precedes the noun with which it has to agree in gender.

High and low span readers differ when processing sentences with long ambiguous regions. While high span readers demonstrate a positivity at the number marked sentence final auxiliary, low span readers do not. The latter finding is compatible with earlier findings (Mecklinger et al., 1995) which demonstrated a positivity (although around 350 ms) only for the case marked auxiliary for readers with high memory span, but not for readers with a low memory span. This absence of a difference in the ERP patterns for subject and object relative clause structures at the sentence final disambiguating auxiliary for low span readers might be taken to suggest that low span readers try to keep both structures active throughout the ambiguous region and therefore do not need to conduct additional structure finalizing processes at the end of the sentence.

7.3. Psycholinguistic modeling

The present ERP results and their interpretation does not seem compatible with the assumptions by MacDonald et al. (1992) who claim that high span readers activate both readings of a temporarily ambiguous structure and that low span readers are less efficient because they only activate one of the possible readings. We

observed no particular reanalysis effect in the ERP data for the low span readers for the non-preferred object-first structures in sentences with long ambiguous regions. Such an effect was predicted on the assumption that low span readers activate only one, namely the simplest structure, when confronted with a temporary ambiguity. MacDonald et al.'s (1992) approach correctly predicts the low span reader's lower accuracy in question answering. In light of the ERP data, however, we claim that the low span readers are less efficient parsers than the high span readers because they do not commit themselves early to one reading when processing sentences with long ambiguous regions. The present results for the high span readers also do not appear to be compatible with models assuming the activation of multiple representations for temporarily ambiguous sentences for high span readers.

The ERP findings for the high span readers rather seem to support the view formulated in the Garden-Path model (Frazier, 1978, 1987) that readers construct one, i.e. the simplest structure compatible with the input when processing temporarily ambiguous sentences. This conclusion is based on the observation of a positivity at the sentence final auxiliary which is taken to reflect processes of reanalysis (Mecklinger et al., 1995) or costs of reprocessing following a Garden-Path (Osterhout and Holcomb, 1992). But note that Frazier (1995) makes this claim for readers and listeners in general and not for high span readers in particular. According to her view differential effects for high and low span readers are due to differences in the reader's motivation to perform the experiment. Up to now, however, empirical support for motivational differences between readers with different reading spans is lacking.

Given the present and earlier findings for high and low span readers we are tempted to propose the following view with respect to their parsing strategies. High span readers are more efficient parsers than low span readers because they commit themselves to a single preferred structure when confronted with structural ambiguities. The present data indicate that when ambiguous sentences with long ambiguous regions are processed by high span readers, only one, namely the subject-first structure is available. Low span readers, in contrast, are less likely to commit themselves early to a particular structure in the presence of a structural ambiguity. Instead, they seem to keep the option for both structures open by leaving the structure they built initially unspecified with respect to the structural relationship between the computed phrases. Although the claim of underspecification must remain a hypothesis at present, the data in general suggest that performing 'low span' might mean to be less efficient in the commitment to preferred structures when confronted with ambiguous information.

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Appendix A. Noun phrases and verbs used to construct the sentence material

1.	Direktor (director)	Sekretär (secretary)	getötet (killed)
2.	Bürger (citizen)	Politiker (politician)	gegrüßt (greeted)
3.	Radfahrer (cyclist)	Jogger (jogger)	gesehen (noticed)
4.	Ingenieur (engineer)	Physiker (physicist)	gesucht (looked for)
5.	Lehrer (teacher)	Schüler (pupil)	geachtet (respected)
6.	Psychiater (psychiatrist)	Zahnarzt (dentist)	gemieden (avoided)
7.	Sänger (singer)	Musiker (musician)	gestört (disturbed)
8.	Komissar (officer)	Mörder (murderer)	gefürchtet (feared)
9.	Läufer (runner)	Turner (gymnast)	geschubst (pushed)
10.	Kellner (waiter)	Koch (cook)	gemocht (liked)
11.	Gastgeber (host)	Freund (friend)	getröstet (consoled)
12.	Schwimmer (swimmer)	Taucher (diver)	gewarnt (warned)
13.	Botschafter (ambassador)	Minister (minister)	geehrt (honored)
14.	Schauspieler (actor)	Regisseur (director)	gemalt (painted)
15.	Anwalt (lawyer)	Buchhalter (accountant)	getäuscht (cheated)
16.	Juwelier (jeweler)	Händler (trader)	geschädigt (harmed)
17.	Erzieher (social teacher)	Alkoholiker (alcoholic)	geschlagen (beaten)
18.	Verkäufer (salesman)	Kassierer (cashier)	gerufen (called for)
19.	Sieger (winner)	Verlierer (loser)	gefunden (found)
20.	Vermieter (house owner)	Makler (estate agent)	geschätzt (esteemed)
21.	Mechaniker (mechanic)	Chemiker (chemist)	gerettet (rescued)
22.	Unternehmer (employer)	Forscher (researcher)	gelobt (praise)
23.	Rentner (pensioner)	Enkel (grandchild)	geküßt (kissed)
24.	Geiger (violinist)	Dieb (thief)	gehört (heard)
25.	Pfleger (nurse)	Arzt (doctor)	geimpft (inoculated)
26.	Richter (judge)	Betrüger (swindler)	gehaßt (hated)
27.	Pförtner (porter)	Gärtner (gardener)	geholt (got for)
28.	Manager (manager)	Trainer (coach)	getadelt (criticized)
29.	Dichter (poet)	Maler (painter)	gepriesen (praised)
30.	Gastwirt (innkeeper)	Winzer (wine grower)	gefördert (promoted)
31.	Redakteur (editor)	Reporter (reporter)	geweckt (woke up)
32.	Segler (yachtsman)	Surfer (surfer)	geärgert (annoyed)

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