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Processing relative clauses varying on syntactic and semantic dimensions: An analysis with event-related potentials

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Event-related potentials were used to study how parsing of German relative clauses is influenced by semantic information. Subjects read well-formed sentences containing either a subject or an object relative clause and answered questions concerning the thematic roles expressed in those sentences. Half of the sentences contained past participles that on grounds of semantic plausibility biased either a subject or an object relative reading; the other half contained past participles that provided no semantic information favoring either reading. The past participle elicited an N400 component, larger in amplitude for neutral than for semantically biased verbs, but this occurred only in the case of subject relative clauses. More specific effects were obtained only for a subgroup of subjects, when these were grouped into fast and slow comprehenders on the basis of their question-answering reaction times. Fast comprehenders showed larger N400 amplitudes for neutral than for semantically biased past participles in general and larger N400s for the latter when there was a bias for an object relative reading as opposed to a subject relative reading. Syntactic ambiguity resolution, indicated by an auxiliary in sentence final position, was associated in this subgroup with a positive component (P345), larger in amplitude for auxiliaries indicating an object relative reading than for those indicating a subject relative reading. The latter component was independent of semantically biasing information given by a preceding past participle. Implications of these findings for models of language comprehension are considered.

Most of the models of language comprehension assume that in forming a representation of a linguistic input the reader or listener exploits grammatical as well as pragmatic knowledge. Although there is general agreement that language comprehension involves the integration of information from lexical, syntactic, and pragmatic sources, there is an ongoing debate with respect to the nature and the timing of the mental processes involved in language comprehension (e.g., Flores d'Arcais, 1990; Frazier, 1987a). One major issue in psycholinguistic research is the stage of processing at which syntactic, semantic, and pragmatic information are made available and integrated to form a final representation of a sentence (e.g., Altmann, 1989; Clifton, Speer, & Abney, 1991; Friederici, 1985; Marslen-Wilson & Tyler, 1980; Mitchell, Corley, & Garnham, 1992).

The best known model postulating priority of syntactic processes during language comprehension is the "garden-path" model proposed by Frazier and colleagues (e.g., Frazier, 1987a, 1987b; Frazier & Rayner, 1982). According to the garden-path model, semantic and pragmatic information cannot influence the initial syntactic analysis of the sentence. Rather, this first syntactic analysis is determined exclusively by a set of syntactic principles (cf. Clifton et al., 1991; Frazier, 1978, 1987b). Only in a second stage is this initial "preferred" syntactic representation evaluated with respect to other information sources, such as semantic and pragmatic information. If later information is inconsistent with the initially favored syntactic structure, a syntactic reanalysis will be initiated (see, e.g., Clifton & Ferreira, 1987; Rayner & Frazier, 1987). In contrast to the garden-path model, "lexical-entry-driven" models claim that information in the lexical entry of a verb—that is, its argument

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structure—is consulted to guide the initial parse (Shapiro, Nagel, & Levine, 1993; Trueswell, Tanenhaus, & Kello, 1993). "Interactive" models suggest that all information sources—that is, semantic/pragmatic and syntactic—continuously interact so that the subject can arrive at the most plausible analysis of a sentence (Marslen-Wilson & Tyler, 1980; Taraban & McClelland, 1988).

In the study reported here, we examined the nature and timing of mental processes underlying language comprehension by recording event-related brain potentials (ERPs) elicited by the presentation of specific parts of a sentence. The ERP is a transient series of recordable voltage oscillations in the brain that occur in response to discrete events. ERPs can provide a record of a subject's response to every word within a visually presented sentence without the intrusive requirement of a manual or verbal response. Moreover, unlike reaction time (RT) measures, ERPs are multidimensional: single ERP components can be distinguished by their latency, amplitude, polarity, and scalp topography. Given that functionally distinct processes are modulated by neuronally distinct brain systems, we would expect their ERP correlates to be different, too. In other words, if, in the course of forming a representation of a linguistic input, syntactic and semantic processes yield different representational levels, the ERP components associated with these processes should be distinct with respect to latency, scalp topography, and/or polarity.

Recent studies in which ERP measures of language processing have been used suggest that the N400, a negative component peaking around 400 msec after stimulus onset that is largest over posterior scalp regions, reflects the ease with which a given lexical element can be integrated in the preceding context. It appears that the amplitude of the N400 is a function of the semantic fit between the target word eliciting the N400 and a prior context (Fischler, Bloom, Childers, Roucos, & Perry, 1983; Fischler & Raney, 1991; Kutas & Hillyard, 1984; Mecklinger, Kramer, & Strayer, 1992). Kutas and Hillyard (1984) found that the amplitude of the N400 elicited by a sentence final word was inversely related to the subjective predictability (i.e., the cloze probability) of this word. It was suggested that the N400 reflects the amount of semantic or lexical priming or constraints from the preceding context for a given target (Fischler et al., 1983; Holcomb & Neville, 1990; Kutas & Van Petten, 1988; Van Petten & Kutas, 1991).

While the role of the N400 as a measure of semantic/lexical integration processes is well established, there is an increasing number of studies identifying ERPs that are associated with syntactic processes during language comprehension. The results of these studies are twofold. First, they have shown that a large variety of syntactic anomalies elicit a parietally focused positive component in the ERP (Hagoort & Brown, 1994; Hagoort, Brown, & Groothusen, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout, Holcomb, & Swinney, 1994). Second, some of these anomalies additionally produce a negativity which is dominant over the left hemisphere (Friederici, Pfeifer, & Hahne, 1993; Münte, Heinze, & Mangun, 1993; Neville et al., 1991; Osterhout & Holcomb, 1992, 1993; Osterhout et al., 1994). Hagoort et al. (1993), in examining electrophysiological correlates of several forms of syntactic anomalies, found a large parietally focused positivity for two of the three violation conditions (subject–verb agreement and word order) when these were encountered in midsentence positions. Osterhout and Holcomb (1992) investigated ERP responses to a syntactic ambiguity between an active sentence and a reduced relative clause in sentences such as *The woman persuaded to answer the door....* The word *to* elicited a large positive-going waveform when it indicated a reduced relative clause analysis of the sentence (as in the example just given), as opposed to when it forced an active sentence analysis (i.e., *The woman struggled to prepare the meal*). More recently, Osterhout et al. (1994) examined ERP responses to verb subcategorization ambiguities (i.e., direct object vs. clausal complement ambiguities) and found large P600 components for words indicating a violation of verb subcategorization frames (i.e., the word *was* in sentences such as *The doctor forced the patient was lying*) or verb subcategorization preferences (the word *was* in sentences such as *The doctor charged the patient was lying*).

Biphasic ERP responses (i.e., left hemispheric negativities followed by positive-going waveforms) to a variety of syntactic anomalies have been found by Neville et al. (1991). Phrase structure violations that were constructed by inverting the order of prepositions and head nouns (e.g., *Ted's about films America*), for example, were correlated with ERP responses including a left anterior negativity peaking at around 400 msec and a centroparietal positivity with a latency of about 700 msec. An early left anterior negativity peaking at around 180 msec was observed by Friederici et al. (1993) in response to a phrase structure violation during auditory comprehension. Another left anterior negativity at around 400 msec was found to be correlated with syntactic word category violations during visual comprehension (Münte et al., 1993).

So far, the available empirical evidence suggests that semantic/lexical integration processes during comprehension are associated with the N400 component, whereas the processing of syntactic anomalies elicits large positive waveforms that sometimes are preceded by left hemisphere negativities. It is noteworthy that syntactic anomalies during comprehension can result from rather different sources. First, syntactic anomalies can be encountered in sentences containing outright violations of the formal constraints of grammar (e.g., violations of subject–verb agreement), rendering the sentence ungrammatical. Second, syntactic anomalies can result from apparent violations of grammatical rules that occur as a function of a particular parsing strategy employed by the individual comprehender. For example, in sentences such as those used by Osterhout et al. (1994) (i.e., *The doctor charged the patient was lying*), a syntactic anomaly emerges at the auxiliary *was* only if the comprehender initially assumes a direct object role of the postverbal noun phrase (see also Osterhout & Holcomb, 1992). In this situation, syntactic anomalies result from parsing strategies employed by the comprehender, even though there is a well-formed analysis of the sentence in principle (i.e., the clausal complement analysis). The empirical evidence on ERP responses to syntactic anomalies so far suggests that both types of syntactic anomalies elicit large positive-going ERP responses. Osterhout et al. (1994), however, found positivities elicited by violations rendering the sentence ungrammatical to be larger than those elicited by violations indicating a less preferred interpretation of the sentence.

THE PRESENT STUDY

We designed the present study in order to examine ERP responses to the resolution of syntactic ambiguities that result from syntactic parsing strategies in well-formed German sentences. The sentences used were subject and object relative clauses. A large number of studies indicate that sentences with object relative clauses, such as Sentence 1 below, are more difficult to process than closely related subject relative sentences such as Sentence 2 (Clifton et al., 1991; Frazier, 1987b; Just & Carpenter, 1992).

The reporter that the senator attacked admitted the error. (1)

The reporter that attacked the senator admitted the error. (2)

Sentence 1 is called an object relative clause because the noun of the main clause (*reporter*) is the object of the relative clause. In contrast, in Sentence 2 the noun of the main clause is also the subject of the relative clause. Unlike in English, in German relative clauses the verb of the relative clause appears in clause final position. In perfect tense, the relative clause ends with a past participle followed by an auxiliary. In addition, in the feminine gender, there is no explicit case marking of the subject and object noun phrases that distinguish nominative and accusative. Furthermore, the feminine relative pronoun *die* is also ambiguous with respect to case (nominative vs. accusative) and number (singular vs. plural). These properties of the German language give the possibility to construct locally ambiguous sentences such as the following:

Das sind die Professorinnen, die die Studentin gesucht hat. (3)

(These are the professors that the student sought has.)

Das sind die Studentinnen, die die Professorin gesucht haben. (4)

(These are the students that the professor sought have).

These two sentences are completely ambiguous with respect to a subject or an object relative reading until the auxiliary (*hat* vs. *haben*) of the relative clause has been encountered. It is the number marking of the auxiliary that indicates that Sentence 3 has an object relative reading (i.e., the noun *professors* is the object of the relative clause), whereas Sentence 4 has a subject relative reading (the noun *students* is the subject of the relative clause).

How do readers deal with local syntactic ambiguities such as those in Sentences 3 and 4? According to the garden-path model outlined above, an initial syntactic structure is assigned on the basis of purely structural information. Frazier (1987b; see also Frazier & Flores d'Arcais, 1989) has provided evidence that readers will initially assign the syntactic analysis of a subject relative clause to sentences such as 3 and 4. This preference is based on a particular parsing strategy, which has been called the "active filler strategy" (see Frazier, 1987b; Frazier & Flores d'Arcais, 1989). According to this strategy, the noun phrase of the main clause in Sentences 3 and 4 will initially be assigned to the gap position right after the relative pronoun *die*, thus yielding a subject relative reading. When the number marking of the auxiliary disambiguates the sentence as containing an object relative clause as in Sentence 3, the initial filler gap assignment has to be revised in the following way: first, the syntactic function of the relative pronoun *die* has to be changed from subject to object, whereas the syntactic function of the following noun phrase has to be changed from object to subject. Second, the object relative pronoun *die* has to be co-indexed with its supposed base position (i.e., gap) to the right of the subject noun phrase. This revision in filler gap assignments should be reflected in a prolongation of the processing and comprehension of the sentence. Empirical support for this assumption has been provided by several studies done with self-paced reading procedures. Reading times in object relative sentences were longer than in subject relative sentences at points at which syntactically disambiguating information became available (Frazier 1987b; Schriefers, Friederici, & Kühn, in press).

In the present study, we addressed two questions. First, we examined to what extent ERPs reflect the processing of local syntactic ambiguities (engendered by parsing strategies proposed for filler gap assignments) during the reading of well-formed relative clauses. As stated above, in the instance of feminine nouns, German relative clauses can be ambiguous with regard to a subject as opposed to an object relative reading until the auxiliary in clause final position is encountered. We hypothesized that if the reader should initially assume the syntactic structure of a subject relative clause (as proposed by the active filler strategy), we would observe a positive component elicited by the disambiguating sentence final auxiliary, whenever the initial filler gap assignment did not map onto the actual structure (i.e., an object relative clause).

Second, we were interested in the impact of semantic plausibility on the assignment of syntactic structure to relative clauses. The structure of relative clauses in German opens the possibility to introduce semantic/pragmatic information with the past participle before syntactic disambiguation on the basis of the auxiliary is possible. For this reason, verbs were chosen for which on grounds of semantic plausibility readers should prefer either a subject relative reading or an object relative reading (e.g., *examine*; it is more likely that professors examine students than that students examine professors). These semantically biased sentences were compared with sentences including verbs that were semantically neutral with respect to a subject or an object relative reading (e.g., *seek*; it is not more likely that professors seek students than that students seek professors). We hypothesized that if subjects used semantic/pragmatic information on-line, semantic integration processes would be less easy for neutral past participles than for biased verb forms, yielding larger N400 components for neutral past participles.

A further prediction for the ERP response to the past participles was derived from the hypothesized active filler strategy. If subjects initially assumed the syntactic structure of a subject relative clause (as predicted by the active filler strategy), we expected that the N400 elicited by past participles that biased toward a subject relative reading would be different from those indicating an object relative reading. In the latter case we predicted a mismatch between syntactic preference and semantic information conveyed by the past participle presumably resulting in more integration difficulty at this point of the sentence. Thus we expected that N400 amplitude elicited by semantically biased past participles would be larger for object relative clauses than for subject relative clauses. The extent to which the semantic information conveyed by the past participle would influence the syntactic preferences (subject vs. object relative clause analysis) and thereby the predicted positivity correlated with syntactic processes would allow clear statements with respect to the independence of syntactic processes.

METHOD

Subjects

Sixteen volunteers (8 male) between 20 and 34 years of age were paid 30 DM to participate in the experiment. All subjects were students from the Free University of Berlin and were native speakers of German. They all had normal or corrected-to-normal vision.

Materials

The stimuli were sentences containing either a subject or an object relative clause. All sentences were of the following structure:

Das ist/das sind die ⟨N1⟩, *die die* ⟨N2⟩ ⟨verb-*ed*⟩ *hat/haben*

This is/these are the ⟨N1⟩, *that the* ⟨N2⟩ ⟨verb-*ed*⟩ *has/have*

where ⟨verb-*ed*⟩ stands for the past participle of the respective verb and N1 and N2 for the two respective nouns.

A total of 32 quartets of two nouns and two verbs were constructed in such a way that one of the nouns was very likely to be the subject of the action given by one of the verbs, whereas the other noun was likely to be the object (e.g., *professor*, *student*, *examine*). The second verb in each of the quartets was determined in such a way that none of the two nouns was more likely to be the agent of the action given by the verb (e.g., *professor*, *student*, *seek*). All the nouns were of the feminine gender. In German this has the consequence that the corresponding relative pronoun (*die*) is ambiguously marked with respect to case (i.e., nominative vs. accusative) and number (singular vs. plural). Moreover, the nouns were also ambiguous with respect to case (nominative vs. accusative). All verbs were transitive verbs requiring a direct accusative object. For each of the quartets eight sentences were derived from a complete crossing of the following three factors: First, the noun in the main clause and the noun in the relative clause were either singular and plural, respectively, or plural and singular, respectively. Second, the verb was either semantically biased or neutral with respect to the two nouns.[1] Third, the sentence final auxiliary was either plural or singular. Table 1 summarizes the eight sentences constructed from each quartet.

For each quartet, four sentences contained a subject relative clause (Sentences 5, 6, 9, and 10). The other four sentences contained an object relative clause (Sentences 7, 8, 11, and 12). Moreover, half of the sentences included a semantically biased verb (Sentences 5–8), and the other half contained a semantically neutral verb (Sentences 9–12).[2] Thus, for each quartet, two sentences (one with a plural auxiliary, the other with a singular auxiliary) could be assigned to the four conditions resulting from a crossing of the factors of bias type (semantic vs. neutral) and relative clause type (subject vs. object). Consequently, each of the four experimental conditions included two sentences, one with a singular auxiliary and one with a plural auxiliary (See Table 1). In order to strengthen the potential impact of semantic/pragmatic information during sentence reading, it was decided not to interleave filler sentences with the relative clause sentences.

After each sentence a question of the following structure was presented:

Wurde die ⟨N⟩ ⟨verb-*ed*⟩ ?

Was the ⟨N⟩ ⟨verb-*ed*⟩ ?

For each of the four conditions, half of the questions referred to N1; the other half, to N2. Therefore, correct answers to the questions were 50% "yes" and 50% "no" within each of the four conditions.

Table 1
Examples of Sentences Used in the Experiment With Literal English Translations

SR, semantic bias	
(5)	Das ist die Professorin, die die Studentinnen geprüft hat. This is the professor that the students examined has.
(6)	Das sind die Professorinnen, die die Studentin geprüft haben. These are the professors that the student examined have.
OR, semantic bias	
(7)	Das ist die Studentin, die die Professorinnen geprüft haben. This is the student that the professors examined have.
(8)	Das sind die Studentinnen, die die Professorin geprüft hat. These are the students that the professor examined has.
SR, neutral bias	
(9)	Das ist die Professorin, die die Studentinnen gesucht hat. This is the professor that the students sought has.
(10)	Das sind die Professorinnen, die die Studentin gesucht haben. These are the professors that the student sought have.
OR, neutral bias	
(11)	Das ist die Studentin, die die Professorinnen gesucht haben. This is the student that the professors sought have.
(12)	Das sind die Studentinnen, die die Professorin gesucht hat. These are the students that the professor sought has.

Note—SR, subject relative clause; OR, object relative clause.

The 32 quartets were assigned to the eight sentence types in such a way that each quartet contributed equally often to each of the four conditions. From the 256 sentences (32 quartets × 8 sentences) a pseudorandomized sequence was formed under the restriction that two sentences of the same condition and two sentences constructed from the same quartet did not occur in direct succession. The 32 noun pairs and the corresponding semantically biased and neutral verbs are listed in the Appendix.

Procedure

The subjects 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. To examine ERP activity elicited by the noun phrases and the past participles over extended periods of time, these elements were always presented for 550 msec and with 550-msec separation from the next chunk. Each trial started with the presentation of a fixation cross in the center of the screen for 300 msec. Five hundred milliseconds after the offset of the fixation cross, the first chunk of the sentence ("Das ist/das sind") was presented for 400 msec. The second chunk, containing the first noun and its article (e.g., *die Professorin*), was displayed 300 msec after the offset of the first chunk with a duration of 550 msec. The third chunk was the relative pronoun of the relative clause. It had a duration of 300 msec and was presented 550 msec after the offset of the preceding chunk. The fourth chunk was the noun phrase (article and noun) of the relative clause presented with 550 msec duration, starting 300 msec after the offset of the preceding chunk. Next, the past participle was displayed with a duration of 550 msec, starting 550 msec after the offset of the preceding chunk. The sixth chunk included the sentence final auxiliary presented with 400 msec duration, 550 msec after the offset of the past participle. Two seconds after the offset of the sentence final word, the question was presented until the subject responded with a button press ("yes" vs. "no") or until 2 sec had elapsed. Each response was immediately followed by a feedback stimulus (600 msec) that informed the subjects about the accuracy of the response (correct/incorrect). The next trial started 1,700 msec thereafter, with the presentation of the fixation cross. The 2,000-msec interval between the offset of the auxiliary and the onset of the question was selected to give the subjects enough time to prepare for the comprehension question.

The words were presented in black letters against a light gray background in the center of the 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 subjects sat at a distance of 70–80 cm from the screen and used the two mouse keys to respond either "yes" or "no" to the question. Response key assignments were counterbalanced across subjects. The subjects 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 in the time interval between the response and the onset of the fixation cross of the next trial. Each subject performed a practice sequence of 24 trials. The experimental sequence consisted of four blocks with 64 sentences. The experimental blocks were constructed so that each block included eight versions of each of the eight sentence types. The blocks were separated by a short break and lasted about 12 min. The entire session, including electrode application and removal, lasted about 2.5 h.

EEG Recording

The EEG activity was recorded by means of a cap (Electro-Cap International) containing 15 tin electrodes. The scalp sites included nine locations based on the International 10-20 System: (Fz, Cz, Pz, F3, F4, T5, T6, O1, O2). Recordings were also taken from six nonstandard locations, including the left and right anterior temporal region (one half of the distance between T3[4] and F7[8]; hereafter, ATL and ATR), 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 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 linked earlobes. The ground electrode was positioned 10% of the nasion-inion distance anterior to Fz. The vertical EOG was monitored with two electrodes located above and below the subject's right eye. The horizontal EOG was recorded between electrodes placed at the outer canthus of each eye. Electrode impedances were kept below 5 kΩ. The EEG and EOG electrodes were amplified by ESMED amplifiers (1.6-sec time constant; upper frequency cutoff at 70 Hz, −3dB/octave rolloff). The EEG and EOG were recorded continuously for each block of trials and were A/D converted with 12-bit resolution at a rate of 256 Hz. Data collection was controlled by an IBM-compatible 386 computer.

Data Analysis

Behavioral data. Reaction time was defined as the interval between the onset of the question and the subject's keypress. All of the RT averages were composed of correct responses. Two of the subjects had an accuracy of less than 55% for the sentences including neutral past participles and were excluded from further analyses. Performance data were quantified in a two-way repeated measures analysis of variance (ANOVA) with bias type (semantic vs. neutral) and relative clause type (object relative vs. subject relative) as factors.

ERP data. ERPs time locked to the past participles for those sentences for which the corresponding question was answered correctly were analyzed from 300 msec prior to the past participle until the onset of the question (i.e., 3,500 msec thereafter). The past participles were selected for the time locking of the ERP data, because up to the onset of the past participles the sentences did not differ with respect to the type of relative clause and the type of bias condition. Thus, any differences in the ERP waveforms as a function of the experimental conditions should have occurred with the start of the presentation of the past participle. The average voltages during the 300 msec preceding the past participles were examined for systematic differences as a function of the experimental conditions. Because no systematic effects were found, the 300-msec interval preceding the past participle was used as a baseline for the ERP amplitude measures. Only sentences for which the question was answered correctly were included in the subject 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. Subject averages were computed separately for each condition and electrode. 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 a latency range following either the past participle or the auxiliary. The latency windows used to quantify the ERP responses will be described in the Results section.

In order to allow an examination of hemispheric differences, the data recorded at the midline electrode sites were treated separately from the data from the lateral recordings. The midline data were analyzed with a three-way repeated measures ANOVA with the factors of electrode (Fz, Cz, and Pz), bias type (semantic vs. neutral), and relative clause type (object vs. subject). For the lateral electrode sites, an ANOVA design including six pairs of lateral electrodes was formulated. The factors were hemisphere (left vs. right), electrode (F3[F4], ATL[ATR], BL[BR], WL[WR], T5[T6], and O1[O2]), bias type (semantic vs. neutral), and relative clause type (object vs. subject relative clause). Because the analysis of multicomponent and multielectrode ERP data involves a large number of statistical tests, there can be a higher risk of Type I errors than in analyses including fewer statistical tests. To deal with this problem, ANOVAs for single electrodes were only performed under the restriction that the "global" ANOVA had provided a significant main effect or interaction for one of the two experimental factors—bias type and relative clause type. 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). Planned pairwise comparisons were performed by using a modified Bonferroni procedure (Keppel, 1991) with alpha set to .03 and .02 for tests involving the midline and the lateral electrodes, respectively.

RESULTS

Behavioral Data

Table 2 presents mean RTs and performance accuracy in each of the experimental conditions. As is apparent from the table, responses were faster to questions following semantically biased sentences than to questions following neutral sentences [$F(1,13) = 22.1, p < .0004$]. No RT effects were found for the factor relative clause type and the interaction of this factor with bias type (both Fs < 1). A similar pattern of results was obtained for the analysis of performance accuracy. Subjects made fewer errors when responding to questions following semantically biased sentences than when responding to questions following neutral sentences [$F(1,13) = 79.34$, $p < .0001$]. Inspection of Table 2 suggests that for neutral sentences subjects were less accurate in the object relative condition than in the subject relative condition (percent correct: 79.2 vs. 85.1), whereas this was not the case for semantically biased sentences (percent correct: 94.3 vs. 94.3). This pattern of results is also supported by the marginally significant interaction of relative clause type and bias type [$F(1,13) = 3.96$, $p < .06$]. Planned comparisons revealed that in the neutral condition subjects made more errors for the object relative clauses than for the subject relative clauses ($p < .02$).

Event-Related Potentials

Figure 1 shows the grand averages of the ERPs in the time interval from the onset of the past participle until the onset of the auxiliary for the subject (Figure 1A) and the object relative clauses (Figure 1B). In each of the plots, the ERPs from the semantic bias condition and the neutral condition are superimposed. As is apparent from the figure, at all electrode sites the ERPs in the four conditions are remarkably similar in the first 400 msec after the onset of the past participle. A negative component (N100) is visible in the first 250 msec after stimulus presentation, preceded by a positivity at the occipital locations (P100). The N100 tended to be largest over central and posterior regions and was followed by a positivity (P200) peaking between 200 and 250 msec. The P200 was largest in amplitude over midline central and frontal locations. This pattern of results is consistent with previously reported results from studies in which visual language stimuli were used (see Neville, Mills, & Lawson, 1992; Osterhout & Holcomb, 1992).

A pronounced negative component with a maximum over the posterior regions can be observed between 400 and 700 msec after the onset of the past participle. On the basis of its scalp distribution and latency, this component will be referred to as N400. Figure 1 shows that in the subject relative clauses the neutral past participles elicited larger N400 amplitudes than did semantically biased past participles. However, in the object relative clauses, large N400 amplitudes were evoked by both types of past participles. The N400 effect for the subject relative clauses appears to have been slightly larger over right posterior regions than over left posterior regions. These observations were confirmed by statistical analyses. The time interval was chosen to encompass the N400 deflection—that is, 400–600 msec. The ANOVA performed on the three midline electrodes revealed an interaction between relative clause type and bias type [$F(1,13) = 5.38, p < .03$]. Two-way ANOVAs performed for each relative clause type separately revealed an interaction of electrode × bias type for the subject relative clauses [$F(2,26) = 3.69, p < .05$]. Planned comparisons revealed a marginally significant effect of bias type for the subject relative clauses at the Pz electrode site ($p < .05$). No reliable differences in N400 amplitude were found for the object relative sentences (Fs < 1). In the ANOVA performed on the lateral electrode sites, the interactions of bias type × relative clause type [$F(1,13) = 3.95, p < .06$] and bias type × hemisphere [$F(1,13) = 3.25, p < .09$] both missed the appropriate significance level.

The finding of no main effect of bias type for N400 amplitude neither for the midline electrodes nor for the lateral electrodes was unexpected. The past participles in the semantic bias condition were chosen in such a way that on grounds of semantic plausibility one of the nouns was likely to be the subject of the action expressed by the past participles, whereas the other was likely to be the object, and the question-answering performance suggests that we had successfully selected such verbs. On the basis of this structure of the sentences, we expected that semantically biased past participles would be more easily integrated into the preceding context, because they would receive more priming from the two preceding nouns than neutral verbs, resulting in smaller N400 amplitudes elicited by semantically biased past participles.

We hypothesized that individual differences in reading comprehension might have contributed to the ob-

Table 2
Mean Question-Answering Times (QAT, in Milliseconds) and Percent Correct as a Function of Bias Type and Relative Clause Type

	Bias Type			
	Semantic		Neutral	
Clause Type	QAT	% Correct	QAT	% Correct
Subject relative	827	94.3	869	85.1
Object relative	821	94.3	889	79.2

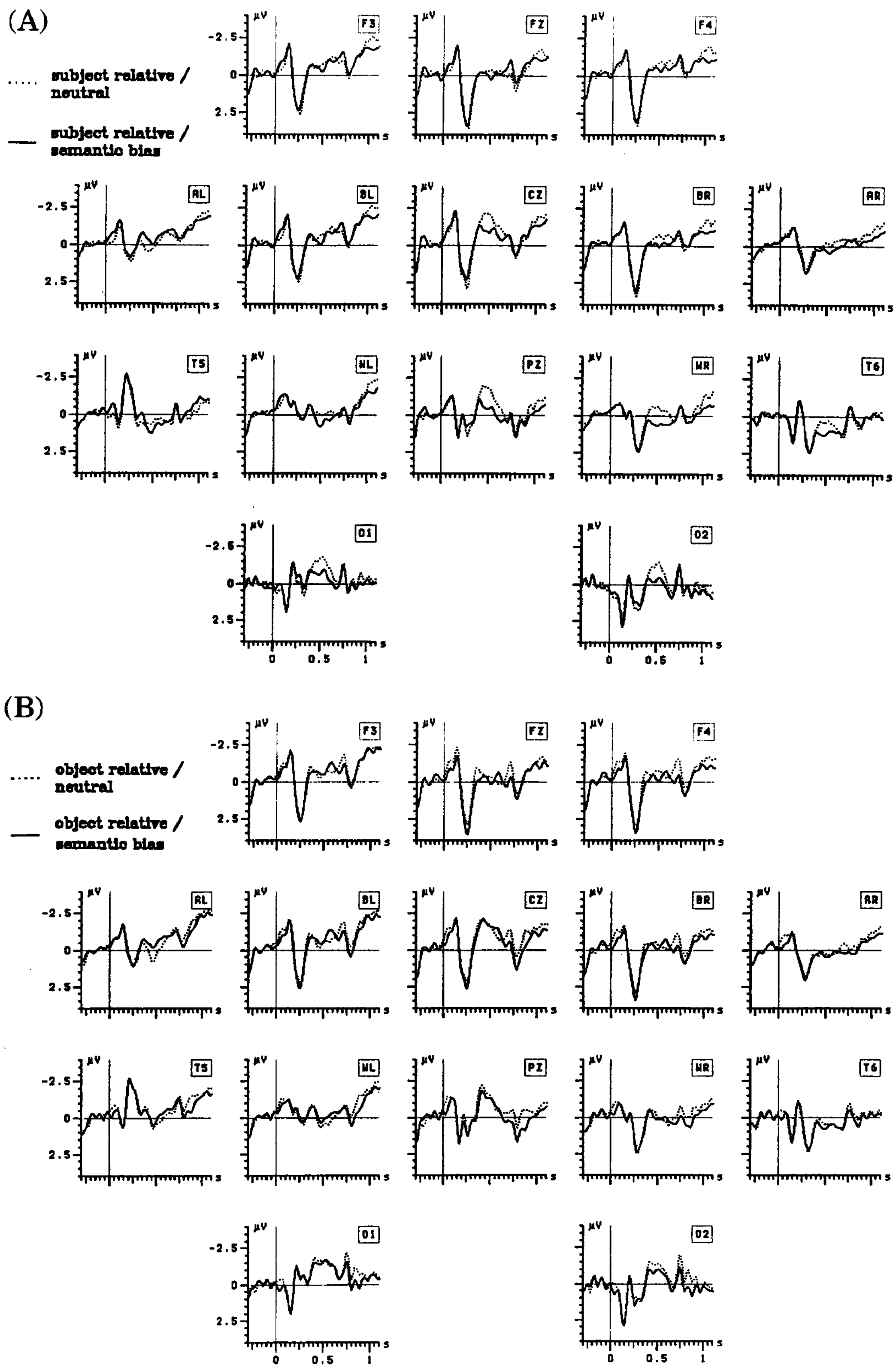


Figure 1. Grand average ERPs elicited by the past participles for the subject relative clauses (A) and the object relative clauses (B). The waveforms are superimposed for the semantic bias and the neutral conditions. The vertical lines indicate the onset of the past participles.

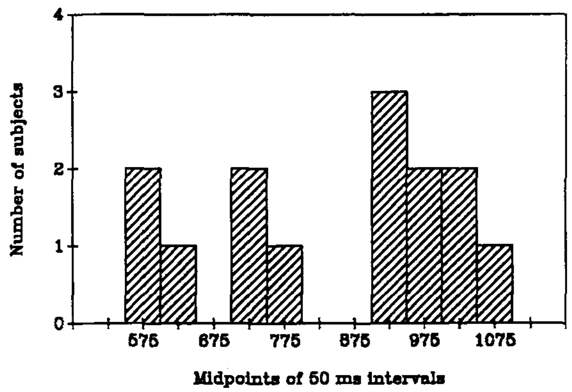


Figure 2. Histograms of mean question-answering times for the 14 subjects. Interval width is 100 msec. Each interval is labeled by its midpoint.

served pattern of results. Figure 2 presents the histogram of the mean response times of the 14 subjects to the questions following each of the sentences.

Figure 2 shows that the response time distribution tends to be bimodal: 6 of the subjects showed fast response times (i.e., < 800 msec), whereas 8 of the subjects were substantially slower in question answering (i.e., > 900 msec). In an effort to examine to what extent individual differences in reading comprehension, as revealed by question-answering performance, contribute to the ERP responses, we split the sample in two groups, one with the 6 fast comprehenders and one with the 8 slow comprehenders.[3]

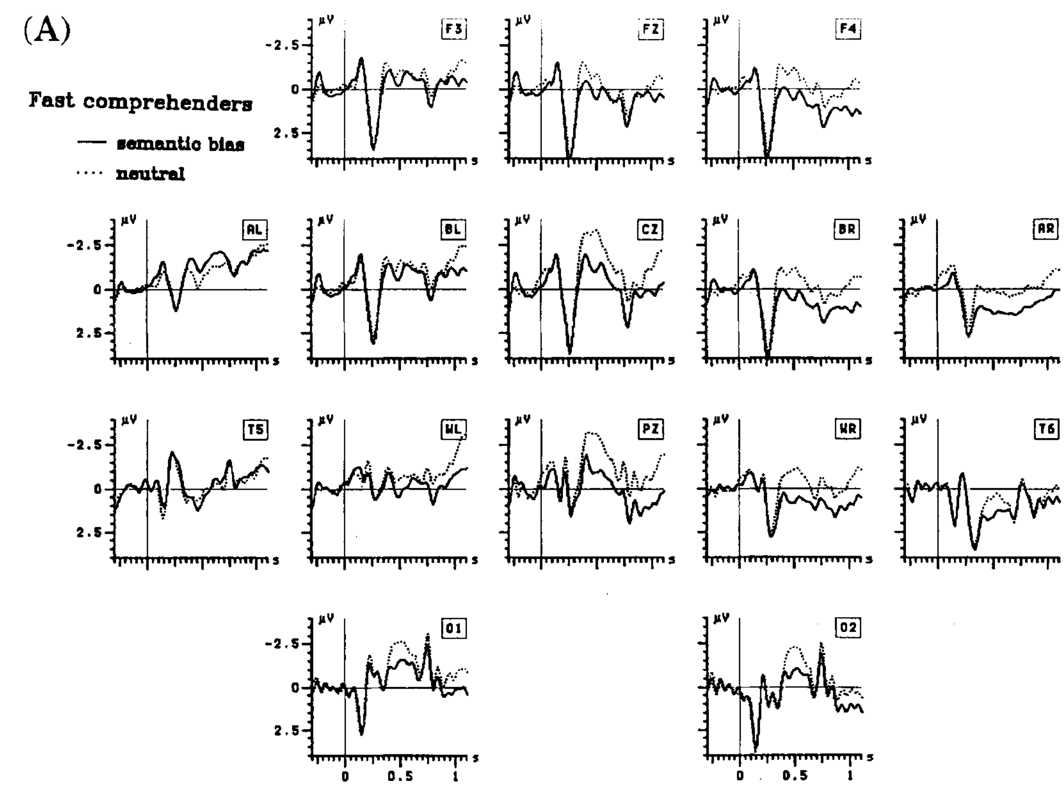
Figure 3 presents the ERPs separately for the fast (Figure 3A) and slow comprehension groups (Figure 3B) collapsed over subject relative and object relative clauses in the time interval from the onset of the past participle until the onset of the auxiliary. The waveforms are superimposed for neutral and semantically biased past participles.

As is apparent from the figure, the waveforms show clear differences between the two groups. First, for the fast comprehenders the P200 component was substantially larger, especially at the frontal and central recording sites. Second, neutral past participles elicited larger N400s than did semantically biased past participles for the fast comprehenders but not for the slow comprehenders. Third, the N400 for the fast comprehenders has a right posterior maximum and is almost absent for the slow comprehenders. A four-way ANOVA with the same factors as in the initial analysis plus a fourth between-subjects factor group (fast vs. slow comprehenders) was performed for the midline electrodes. This ANOVA revealed interactions between bias type and group [$F(1,12) = 7.34$, $p < .01$] and between bias type, electrode, and group [$F(2,24) = 4.49$, $p < .02$]. Thus, the two groups have to be treated separately. For the fast comprehenders a main effect of bias type [$F(1,5) = 11.89$, $p < .01$] was found. Furthermore, the interactions of bias type × electrode [$F(2,10) = 4.14$, $p < .06$] and bias type × relative clause type [$F(1,5) = 5.21$, $p < .07$] were marginally significant. ANOVAs performed separately for the two bias type conditions revealed larger N400 amplitudes for the object relative clauses than for the subject relative clauses for the semantically biased condition [$F(1,5) = 8.85$, $p < .03$], but not for the neutral condition ($F < 1$). This pattern of results is further illustrated in Figure 4 and Table 3 for the electrode where N400 amplitude was largest—that is, Cz. For the slow comprehenders, neither an effect of bias type nor an interaction of bias type and electrode was obtained (Fs < 1).

The data from the lateral electrodes were also quantified in an ANOVA design with the additional between-subjects factor of group (fast vs. slow comprehenders). This analysis revealed the following interactions: group × hemisphere [$F(1,12) = 4.48$, $p < .05$], bias type × group [$F(1,12) = 5.61$, $p < .03$], bias type × hemisphere × group [$F(1,12) = 6.03$, $p < .03$], and bias type × hemisphere × electrode × group [$F(5,60) = 4.32$, $p < .003$]. ANOVAs performed separately for each group revealed an effect of bias type [$F(1,5) = 7.49$, $p < .04$] and an interaction of bias type, hemisphere, and electrode [$F(5,25) = 2.78$, $p < .03$] for the fast comprehenders. ANOVAs performed for each of the hemispheres separately revealed larger N400s for the neutral past participles than for the semantically biased past participles for the right hemisphere electrodes ($p < .02$), but not for the left hemisphere electrodes ($p = .15$). No effects were found for the slow comprehenders (Fs < 1).

A closer visual inspection of Figures 3 and 4 suggests a negative going wave between 700 and 1,100 msec after the onset of the past participle—that is, in the last 400 msec prior to the onset of the auxiliary. This negativity is widely distributed, but largest frontocentrally. In contrast to the N400, it appears to be left lateralized. This auxiliary preceding negativity was quantified as the mean voltage within the 400 msec preceding the onset of the auxiliary. The ANOVA performed for the midline data revealed an interaction of bias type × group [$F(1,12) = 5.82$, $p < .03$]. Planned comparisons revealed that the negativity was smaller for the fast comprehenders than for the slow comprehenders at the Fz electrode ($p < .03$) for the semantic bias condition. No reliable between-group differences were found for the neutral condition. ANOVAs performed for each of the groups separately revealed larger negativities for the neutral than for the semantically biased past participles for the fast comprehenders [$F(1,5) = 10.70$, $p < .02$], whereas for the slow comprehenders no effects of bias type could be observed ($F < 1$). In the ANOVA for the lateral electrodes, a main effect of hemisphere was found [$F(1,12) = 18.51$, $p < .001$], suggesting that the auxiliary preceding negativity was larger over the left hemisphere. Furthermore, the factors hemisphere and group interacted [$F(1,12) = 11.64$, $p < .005$]. For the fast comprehenders the negativities were larger over the left hemisphere [$F(1,5) = 40.97$, $p < .001$], whereas no hemisphere effects were found for the slow comprehenders [$F(1,7) = 0.03$, $p > .563$].

Figure 5 presents the ERPs in the time interval concerning the processing of the disambiguating auxiliary—



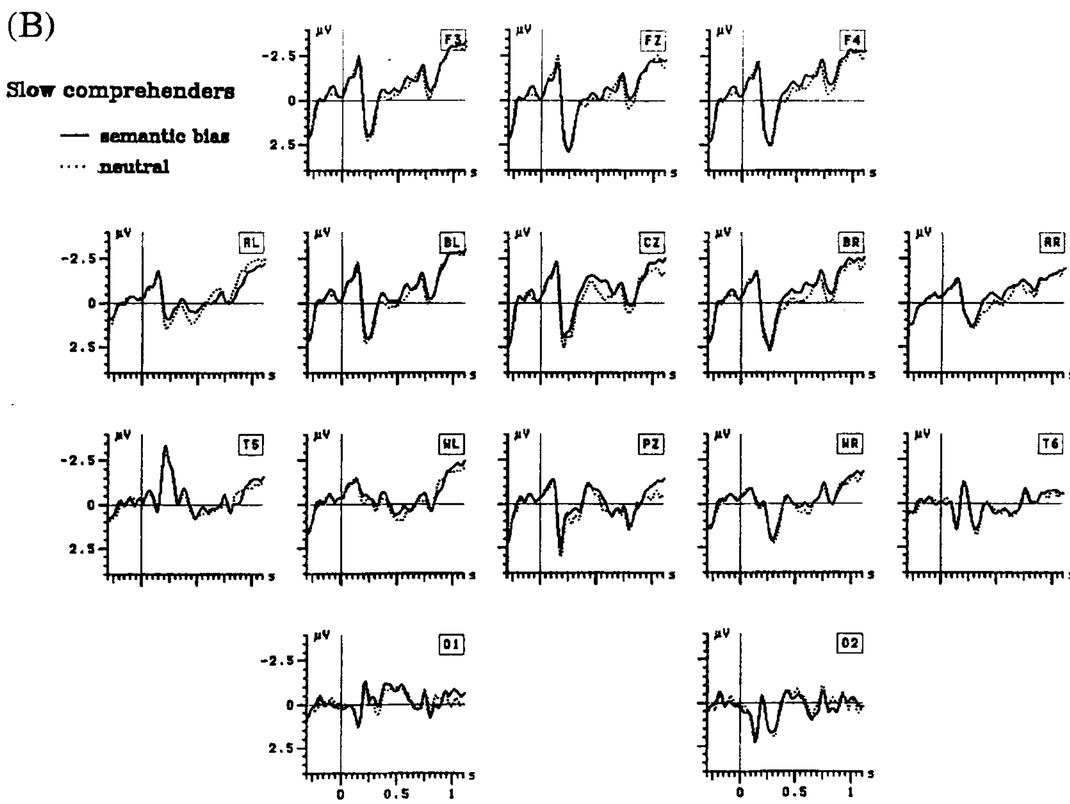


Figure 3. Grand average ERPs elicited by the past participles separately for the fast comprehenders (A) and the slow comprehenders (B). The waveforms are superimposed for the semantic bias and the neutral condition.

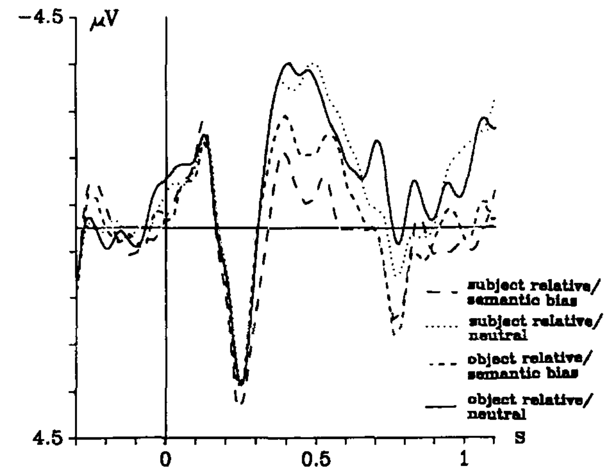


Figure 4. Grand average ERPs elicited by the past participles at the Cz electrode site for the fast comprehenders. The waveforms are superimposed for the four experimental conditions. The onset of the past participle is indicated by the vertical line.

from 100 msec preceding until 900 msec after the onset of the auxiliary at the three midline electrodes for the fast comprehenders. The waveforms are superimposed for the subject relative clauses, and the object relative clauses are collapsed over semantically biased and neutral sentences.

The ERPs show a sharp positive component peaking between 300 and 400 msec after the onset of the auxiliary. This component became increasingly positive from the anterior to the posterior recording sites. Based on its mean latency at the Pz electrode, this component will be referred to as P345.[4] It was quantified as the mean voltage within the latency window of 300–400 msec after the onset of the auxiliary. For the fast comprehenders, the P345 was larger in amplitude for the object relative clauses than for the subject relative clauses [$F(1,6) = 7.90$, $p < .03$]. Most interestingly, there was no interaction of relative clause type and bias type. For the slow comprehenders, no effect of relative clause type was found [$F(1,6) = 1.36$, $p > .29$]. No reliable effects of bias type were observed for the two groups.[5] This pattern of results for both of the comprehension groups is illustrated further in Figure 6.

The ANOVA for the lateral electrodes revealed an effect of group [$F(1,12) = 7.84$, $p < .01$], suggesting that at the lateral electrodes the P345 was larger for the fast comprehenders than for the slow comprehenders. Furthermore, main effects of electrode [$F(5,60) = 8.50$, $p < .001$] and hemisphere [$F(1,12) = 29.08$, $p < .002$] were obtained, but no interaction with group and/or relative clause type was found for the P345 at the lateral electrodes.

Table 3
Mean N400 Amplitude in Microvolt (*SE*) at the Cz Electrode for the Fast Comprehender Group in the Four Experimental Conditions

	Bias Type			
	Semantic		Neutral	
Clause Type	*M*	*SE*	*M*	*SE*
Subject relative	−0.69	.54	−2.98	.80
Object relative	−1.76	.58	−2.80	.79

DISCUSSION

In the present study, we examined the processing of locally ambiguous sentences varying in semantic plausibility. For the question-answering performance, a substantial effect of semantic bias induced by the main verb was found. RTs were shorter and accuracy higher for questions that followed a semantically biased relative clause than for questions following a relative clause including a neutral past participle. This result suggests that the semantic bias was strong in the present experiment and that subjects relied on the semantic/pragmatic information carried by the main verb (past participle) in constructing a final interpretation of the sentences. With respect to the syntactic format of the relative clauses, the results for the question-answering performance were less consistent. RT did not differ between the subject and the object relative clauses. However, in the neutral condition, performance accuracy was lower for the object relative clauses than for the subject relative clauses.

A more detailed picture of the processing of syntactic and semantic information during reading comprehension is provided by the analysis of the ERP data. The main finding of the present experiment was that different aspects of language processing during the comprehension of relative clauses were associated with different ERP responses. Reading of the past participle, which, in the semantic bias condition, provides lexical-semantic information with respect to either a subject relative or an object relative reading of the sentence is associated with a right lateralized posterior N400 with a peak latency of about 500 msec. In contrast, the processing of the sentence final auxiliary, which resolves syntactic ambiguity, evokes a centroparietal distributed positivity with a peak latency of 345 msec.[6]

Individual Differences

Before turning to a discussion of the ERP results, we will comment on the substantial ERP differences found for the defined fast and slow comprehension groups. The P200 component elicited by the past participle was larger for the fast comprehension group. Given its exogenous nature, differences in P200 amplitude might indicate the presence of altered stimulus processing at early stages for the fast comprehension group (cf. Johnson, 1992; but see comments in note 7).

The ERP differences related to relative clause type and semantic bias were larger and more consistent for subjects with fast responses during question answering than for subjects with slower responses. It has repeatedly been argued that individual differences in reading comprehension result from differences in working memory capacity (Just & Carpenter, 1992; King & Just, 1991;

Martin, 1987; Martin & Feher, 1990). King and Just (1991) emphasized that language comprehension processes rely on the temporary storage of words and syntactic representations, so that working memory capacity plays a central role in language comprehension (see Raney, 1993, for related arguments). Evidence for this view is provided by a study evaluating self-paced reading times for object relative clauses and subject relative clauses. The main findings were that subjects with low working memory capacity took longer in reading more complex parts of the sentences (i.e., two consecutively presented verbs) and had a poorer comprehension accuracy in answering true–false comprehension questions (cf. Just & Carpenter, 1992). Working memory capacity was measured by a reading span test developed by Daneman and Carpenter (1980) (for a detailed description of the reading span test, see Daneman & Carpenter, 1980; King & Just, 1991; Turner & Engle, 1989).

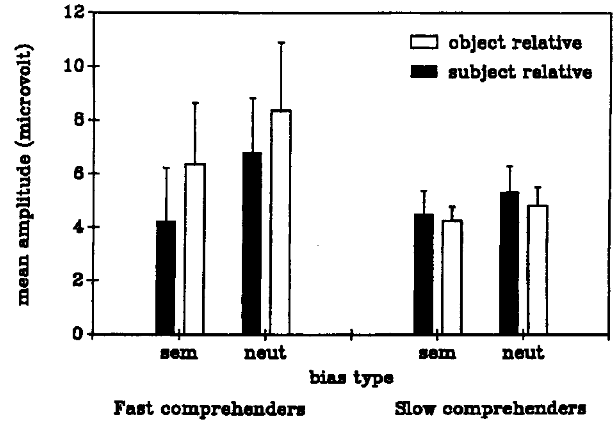


Figure 6. Mean P345 base-to-peak amplitude (+1 *SE*) elicited at the Pz electrode in each of the four experimental conditions for the fast (left panel) and the slow (right panel) comprehenders.

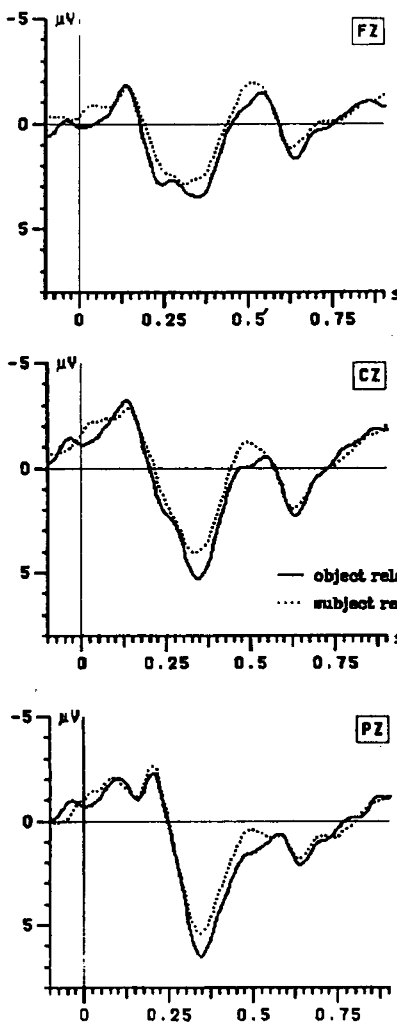


Figure 5. Grand average ERPs elicited by the auxiliaries in sentence final position for the fast comprehenders. The waveforms are superimposed for the subject relative and the object relative clauses. The vertical lines indicate the onset of the auxiliaries. Note that the 300 msec preceding the past participle served as a baseline for the waveforms.

To examine whether the individual differences observed for response speed in the present study were correlated with individual differences in working memory capacity for language materials as revealed by the reading span test, we performed a post hoc reading span test with all our subjects. This reading span test was similar to the one employed by King and Just (1991), but adapted to German. The correlation between the reading span scores and the response times for question answering was −0.51 ($p < .05$), suggesting that the response times to the questions in this study share common variance with measures of memory capacity for language. In this context, it is also worth mentioning that the slow and fast comprehenders reported rather different strategies during reading. The fast, but not the slow, comprehenders reported "passivation" strategies with which they matched the voice of the question, which was passive. By doing so, they were able to match the object noun with the upcoming noun in the question. Besides differences in memory capacity for language materials, these different strategies in approaching the task might be another source of the substantial interindividual differences in response speed during question answering. These interindividual differences in comprehension performance go together with pronounced ERP differences between the two comprehension groups, suggesting that interindividual differences in comprehension performance are correlated with differential electrophysiological processes. In what follows, we will discuss the ERP results separately for the two groups.

Semantic and Syntactic Processes: The N400

For the fast comprehension group, processing of the past participle was associated with a posterior N400. This N400 was larger in amplitude for the neutral past participles than for the biased past participles. This difference was largest at central and parietal locations and was slightly but significantly larger over the right hemisphere. These results suggest that processing of the two nouns facilitates the lexical activation of the semantically related past participles as opposed to the neutral past participles. In the latter case, the past participle is presumably less constrained by the preceding context, so that more effort is required in order to activate the lexical item (Holcomb, 1993). This interpretation is consistent with a large number of studies in which it has been shown that the N400 is associated with the difficulty in integrating a lexical element in a semantically constraining sentence context (Bentin, Kutas, & Hillyard, 1993; Bentin, McCarthy, & Wood, 1985; Friederici et al., 1993; Kutas & Hillyard, 1984; Rösler, Friederici, Pütz, & Hahne, 1993). The results also indicate that the fast comprehenders used the semantically constraining information at this point in the sentence.

Besides this semantic N400 effect, we also found a syntactically induced N400 amplitude difference for the fast comprehenders. That is, in the condition with semantically biased verbs, the same past participles elicit a larger N400 when they bias toward an object relative reading than when they bias toward a subject relative reading of the sentence. Although the voltage differences between the two relative clause type conditions were only about 1.1 μV, the proportion of explained variance (ω^2 = .52) suggests that the effect is reasonably strong. To interpret this result, it is important to recall that the two relative clause types differed only with respect to the order of the two nouns preceding the past participle. An explanation for this N400 effect might be that readers initially assume the syntactic structure of a subject relative clause. When the past participle is encountered in the subject relative condition, the chosen syntactic preference and semantic information are consistent, resulting in less effort to integrate the past participle's semantic information. In contrast, in the object relative condition, the initially preferred syntactic structure does not match the semantic information carried by the past participle. In this instance, the past participle receives less priming from the preceding context, resulting in more effort to integrate the past participle.

These conclusions have to take into account the particular experimental situation under which data were gathered—namely, that (1) all sentences used in the experiment contained relative clauses (i.e., no filler sentences were used) and (2) the comprehension questions asked during the experiment may have made the distinction between subject and object relative clauses quite salient. Thus, on the one hand, the subjects presumably were more aware of the structural options provided by the sentences in the experimental situation than they might have been in normal reading situations. But, on the other hand, these two aspects of the experimental design presumably stressed the availability and usefulness of information for the readers. In fact, since each sentence contained the same sort of ambiguity and the comprehension question demanded the resolution of this sort of ambiguity, we assume that the relevance of the semantic information carried by the verb became even more obvious for the subjects. Keeping these considerations in mind, we will now turn to the interpretation of the results obtained for the processing of syntactic information.

Syntactic Processes: The Positivity at 345 Milliseconds

The auxiliaries in sentence final position elicit a positive component with a mean latency of 345 msec. This P345 component became increasingly positive from the frontal to the parietal recording sites and for fast comprehenders differed as a function of relative clause type, being more positive for object relative clauses than for subject relative clauses. It is important to note that this difference in P345 amplitude was observed for both bias type conditions.

It has been argued repeatedly that words in sentence final position that are perceived to be syntactically anomalous elicit negative-going deflections in the ERP starting at about 200–300 msec poststimulus (cf. Friederici et al., 1993; Osterhout & Holcomb, 1992; Van Petten & Kutas, 1991). On the basis of the latter findings the P345 effect could be interpreted as an increased negativity elicited by the sentence final auxiliary in the subject relative sentences. This interpretation, however, presupposes that the subject relative clauses are perceived to be syntactically more anomalous than the corresponding object relative clauses. There is strong empirical evidence that makes this assumption very unlikely: First, examination of the question-answering performance (cf. Table 2) reveals that for the neutral condition performance accuracy was substantially better for the subject relative than for the object relative sentences. Second, in a self-paced reading task conducted with the same sentence materials, shorter reading times for the auxiliary were observed when it indicated a subject relative reading as opposed to an object relative reading, independently of the semantic information conveyed by the past participle preceding the disambiguating auxiliary (cf. Schriefers et al., in press). In addition to the results reported by Frazier (1987a), these two observations can be taken as evidence of a clear preference for the subject relative reading of ambiguous relative clauses. Thus, it is rather unlikely that subject relative sentences were perceived as being syntactically more anomalous and hence more difficult to interpret.

A second, more likely, interpretation for the P345 effects can be derived from the assumption that the comprehender initially selects the less complex syntactic structure (i.e., the subject relative reading), as suggested by Frazier (1987b). Thus, the larger P345 components observed for the object relative sentences for the fast comprehenders seem to reflect the need for a syntactic reanalysis that occurs when a perceived syntactic structure (i.e., an object relative) does not map onto the one initially selected (i.e., a subject relative). This interpretation of the P345 effect is consistent with results of previous ERP studies on syntactic ambiguities (Osterhout & Holcomb, 1992; Osterhout et al., 1994) which have shown that encountering a disambiguating part of a sentence that forces a less preferred syntactic analysis is associated with a centroparietal positivity in the ERP. However, in contrast to the positivities found in the studies mentioned above that had an onset of about 500 msec and a duration of several hundred milliseconds, the P345 is a sharp wave with little latency variability.

An explanation for the apparent difference in the onset and the duration between the P345 and other positivities elicited by syntactic anomalies resulting from parsing strategies employed by the comprehender could be that perceiving syntactic anomalies of different kinds can lead to rather different consequences for the comprehender. To illustrate this point, consider the active/relative clause ambiguity examined by Osterhout and Holcomb (1992) (e.g., *The woman persuaded to answer the door*). If one assumes that the parser initially constructs an active interpretation of the sentence (i.e., *The woman persuaded someone*), reading the word *to* indicates a violation of the subcategorization properties of the verb *persuade* and forces the comprehender to construct a more complex syntactic analysis as a relative clause (i.e., *The woman that was persuaded to*...). Thus, encountering the anomaly results in a fundamental change in the hierarchical syntactic structure (i.e., the phrase structure tree) of the sentence. The same is true for the direct object clausal complement analyses in the Osterhout et al. study (1994).

In contrast, reading the sentence final auxiliary in the relative clause sentences used in the present study indicates either a correct or an erroneous filler gap assignment. That is, according to the active filler strategy (Frazier & Flores d'Arcais, 1989), the gap position directly after the relative pronoun *die* will initially be co-indexed with the noun phrase of the main clause, resulting in a subject relative reading of the sentence. When the auxiliary disambiguates the sentence as being an object relative clause, it forces the gap position after the noun phrase of the relative clause to be co-indexed with the noun phrase of the main clause. In contrast to structure-changing processes involved in the derivation of a reduced relative clause analysis from an initial syntactic analysis as an active sentence, the revision of a filler gap co-indexing in German relative clauses preserves the hierarchical phrase structure of the sentence (for a detailed description of the mechanisms underlying filler gap assignments, see Frazier, 1987b; Frazier & Flores d'Arcais, 1989).

On the basis of these considerations and of the apparent differences in onset and duration of positivities elicited by different syntactic anomalies, it is not unlikely that the less complex syntactic reanalysis (i.e., revisions of filler gap assignments with preserved hierarchical phrase structures) is (1) applied more rapidly and (2) associated with less processing load than those syntactic reanalyses that require a fundamental change in the hierarchical phrase structure of the sentence (i.e., active vs. relative clause analysis of a sentence). This interpretation concerning the processing load is consistent with the proposal that the amplitude of positivities elicited by syntactic anomalies reflects the processing load associated with a syntactic reanalysis rather than the detection of a syntactic anomaly per se (cf. Osterhout et al., 1994). The notion that the latency of the positivities elicited by syntactic anomalies is related to the processing time needed for reanalysis must await further independent evidence.

It should be noted that this interpretation makes no explicit assumption about the precise nature of the syntactic "reanalysis process." Is it that the new structure becomes available immediately after the initial structure has been disproved by some elements, since the system still has all the phrasal information and only needs to provide new structural attachments? Or is it that the alternative structure becomes available by the reactivation of the less preferred and therefore less active structure computed in parallel with the preferred one (Hickok, 1993)? Whatever the final decision about this issue might be, the observation that syntactic reanalysis is associated with positive components in the ERP that vary in amplitude and latency as a function of the complexity of the required reanalysis at least suggests that a resetting and/or updating of a current structure in working memory is essential for any proposed structural reanalysis process.

The P345 for the slow comprehenders differs in two respects from the P345 in the fast comprehension group. First, the slow comprehenders' P345 was smaller in amplitude (as measured at the lateral electrodes). Second, no differences were found for the two syntax conditions. Recent behavioral studies have demonstrated that poor comprehenders (i.e., as revealed by reading span scores) show stronger garden-path effects in spite of semantic constraints than do good comprehenders when reading English sentences (Just & Carpenter, 1992; but see King & Just, 1991). Given that the larger P345 found for the object relative condition in the present study was interpreted to reflect syntactic reanalysis processes emerging from incorrect initial syntactic assignments, the absence of a P345 effect for the slow comprehenders seems surprising at first glance. One explanatory assumption could be that slow comprehenders may initially have assumed a subject relative reading of the sentences, but that disambiguating syntactic information provided by the auxiliary may simply not be processed immediately and exhaustively when one is reading the auxiliary. That is, slow comprehenders may postpone the syntactic reanalysis enforced by number information of the auxiliary (singular vs. plural) to a later point in time. That the syntactic information carried by the auxiliary is available to slow comprehenders at some later point in time is revealed by their question-answering performance. The notion that slow comprehenders use the disambiguating information encoded in the auxiliary to a lesser extent while reading the auxiliary is also supported by the smaller P345 components found in this group.[7]

Finally, we will comment on the relationship between the P345 and the P300 component that is often observed following unexpected events (Donchin & Coles, 1988; Johnson, 1986; Mecklinger & Ullsperger, 1993). Like the P300 component, the P345 has a central-parietal maximum and is elicited when events indicate that there is a need to modify or update a current operating model of the environment (Donchin, 1981). On the basis of these topographical and functional similarities between P300 components elicited by nonlinguistic stimuli and the P345 observed in this study, we conclude that the P345 is very likely a member of the P300-like waveforms.

Memory Processes: The Negativity Following the N400

An important question is whether the semantic information of the past participle in the semantic bias condition can have a direct influence on the initial syntactic analysis, either by changing the actual subject relative analysis to an object relative analysis (the garden-path model) or by deactivating the syntactically preferred but semantically implausible subject relative analysis (in case of a parallel parsing model; see, e.g., Hickok, 1993). The results of the P345 clearly speak against such a direct influence. The P345 amplitude is larger for auxiliaries requiring an object relative analysis as opposed to a subject relative analysis, independently of the semantic bias.

But how does the latter interpretation fit with the observed negativity after the N400? This negativity had an onset at about 750 msec after the past participles and lasted until the onset of the auxiliary. It was most pronounced at frontal and central electrodes and, in contrast to the N400, largest over the left hemisphere. Thus, this negativity shows functional and topographical similarities to other negative components that appear to be specific for working memory operations that include aspects of language (Kluender & Kutas, 1993; Lang et al., 1987; Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992). For example, Ruchkin et al. (1992) found the amplitude of a left frontal negativity to be correlated with working memory load during phonological memory operations. Kluender and Kutas (1993) found the amplitude of a left frontal negativity to be related to working memory load during filler gap assignment operations. In our study the negativity was smaller in amplitude for the semantic bias condition than for the neutral condition for the fast comprehenders, but equally large for both bias type conditions for the slow comprehenders. Given a working memory interpretation, this implies that for the fast comprehenders the semantically neutral sentences require more working memory capacity after the past participle than do the semantically biased sentences. If one assumes that the syntactic parser initially proposes both possible syntactic analyses in parallel, and that the semantic information carried by the past participle deactivates the semantically inappropriate syntactic analysis, one would indeed expect a higher working memory load for the neutral condition, since in this condition two syntactic structures have to be kept active in working memory. But this interpretation stands in clear contradiction to the P345 results: under the assumptions just made, a difference in P345 amplitude between subject and object relative sentences should occur only for semantically neutral sentences, not for semantically biased sentences. The present data, however, show that the syntactic P345 effect (subject vs. object relative clause) is independent of the preceding semantic information carried by the past participle (bias vs. neutral). Given these data, we conclude that the observed difference in the negativity following the N400 and preceding the auxiliary-related P345 cannot be attributed to a difference in the number of syntactic analyses kept active in working memory.

It could be argued that the negativity prior to the auxiliary is associated with preparatory processes related to the upcoming auxiliary. This interpretation would be consistent with studies in which "stimulus-preceding negativities" have been found to be correlated with the amount of information delivered by the upcoming stimulus (Chwilla & Brunia, 1991; Damen & Brunia, 1987; see also Rösler, 1991). But in contrast to the negativity in our study, these stimulus-preceding negativities were found to be maximal over parietal and occipital regions when visual stimuli were anticipated. This obvious dissimilarity in scalp distribution makes a preparatory interpretation of this negativity very unlikely.

An alternative, though admittedly speculative, account would attribute the observed differences in the negativity following the N400 to differences in working memory load at the semantic level. According to such a view, in the semantically neutral condition the fast as well as the slow comprehenders keep two semantic representations in working memory—namely, NP1 does something with NP2, and NP2 does something with NP1. In the semantically biased condition, by contrast, the fast comprehenders use the semantic information carried by the past participle to deactivate the implausible one of these two semantic representations, thus keeping only one semantic representation in working memory. The slow comprehenders, by contrast, do not use the semantic information to deactivate one of the semantic representations. Rather, they keep both semantic representations in working memory. As a consequence, for the slow comprehenders the negativity should be equally pronounced for semantically biased and neutral sentences, and it should be of approximately the same size as the negativity for the neutral condition in the fast comprehenders. And this is indeed what the data show.

Implications of the Electrophysiological Data for Psycholinguistic Models of Sentence Comprehension

The present ERP data together with those of related studies suggest the following description of the temporal structure of the processes involved in the comprehension of relative clauses in a verb final language such as German. When encountering the possible gap position between the relative pronoun *die* and the noun phrase of the relative clause, the reader appears to assign the noun phrase of the main clause to this gap position as predicted by the active filler strategy (Flores d'Arcais, 1990; Frazier, 1987a). This notion is supported by the larger N400 amplitudes elicited by biasing verbs that indicate an object relative reading than by biasing verbs that indicate a subject relative reading. Moreover, the N400 differences between the neutral and the semantically biased past participles suggest that readers perform a semantically based analysis on line and in parallel with the syntactic analysis. The notion that semantic information is processed in parallel with syntactic information is also supported by the observation that for the fast comprehenders the negativity preceding the auxiliary was substantially smaller after semantically biased past participles than after neutral past participles.

An important question is whether this semantic analysis is used to revise the initial syntactic analysis on line—that is, before the auxiliary is encountered. The observation that the P345 component for the sentence final auxiliaries was larger for object relative than for subject relative sentences independently of the semantic bias of the preceding past participles suggests that the readers do not revise their initial syntactic analysis despite semantic constraints. This interpretation is also supported by the results of a self-paced reading study with the same materials (Schriefers et al., in press, Experiment 3) in which longer reading times for auxiliaries indicating an object relative reading were found despite semantic information carried by the immediately preceding past participle.

A model accounting for these data would have to assume that the initial parse is exclusively structurally guided and either computes only one syntactic analysis or activates both possible structures in parallel, but with a clear preference for the syntactically least complex one. Furthermore, a semantic analysis is conducted in parallel with and largely independently of the syntactic analysis. In the course of this analysis, semantic information may activate plausible and deactivate implausible semantic representations. These semantic analyses do not have any direct and immediate influence on the current syntactic analysis. It is only when the syntactically disambiguating information is encountered that an inappropriate syntactic analysis is dismissed. Further research on parsing processes in language comprehension using ERP measures should be able to determine the specific temporal parameters of a given syntactic structure's activation status on line.

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NOTES

1. The selection of biased verbs was based on a paper-and-pencil study in which subjects ($n = 12$) were asked to generate short sentences on the basis of two nouns and a verb. The order of presentation of the two nouns was counterbalanced across subjects. For the verbs selected, 95% of the subjects' responses were consistent with the assumed bias.

2. Given the restrictions on the materials (two feminine nouns plus two verbs, one with a clear bias and one neutral), the two nouns and verbs were repeated in each of the experimental conditions. The repetition of the same verbs in the subject and the object relative conditions could reduce the differences between the two conditions in comparison with a multiple-list design in which each subject sees only one version of each verb on a particular stimulus list.

3. Besides being slower in question answering, the subjects in the slow comprehender group also tended to make more errors especially in the more difficult semantically neutral conditions. Performance accuracy in these conditions was 84% and 78% for the fast and slow groups, respectively. However this difference was not statistically reliable [$F(1,12) = 2.37, p < .14$].

4. As is apparent from Figure 5, the P345 was followed by a fronto-central negativity which was slightly larger in amplitude for the subject relative sentences in the time interval from 450 to 550 msec after auxiliary onset. On the basis of this observation, it could be argued that the effects found in the preceding P345 interval emerge from the differences in the latter (450–550 msec) interval. ANOVAs performed on mean amplitude measures in this time interval did not reveal reliable differences between the two relative clause type conditions, suggesting that this interpretation is extremely unlikely.

5. The analyses of the ERPs evoked by the past participles yielded substantial ERP differences extending until the onset of the auxiliary. These effects might confound the quantification of the P345 using a pre-auxiliary baseline. Thus a baseline preceding the past participle was considered to be more reliable for the quantification of the P345. We also quantified the P345 by means of baseline-to-peak measures. In this analysis, the P345 was defined as the maximum positive de-

flection relative to the pre-participle baseline in a latency window from 300 to 500 msec after the auxiliary. The results of this analysis did not differ in any significant respect from those obtained in the initial analysis of the P345.

6. It could be argued that the differences in P345 amplitude are not a genuine response to the auxiliary but rather result from a spillover of preexisting ERP differences. The auxiliary was preceded by the verb, which elicited an N400 and a subsequent negativity. However, in the past participle interval the only ERP difference related to relative clause type was a larger N400 for object relative than for subject relative clauses in the semantic bias condition. For the subsequent negativity preceding the auxiliary, no effects of relative clause type were observed. Moreover, the N400 was most pronounced over the posterior right hemisphere electrodes, and the negativity preceding the auxiliary had a left central maximum. No signs of laterality were observed for the P345. On the basis of these observations, it is very unlikely that the P345 differences spilled over from the verb epoch.

7. Several precautions have to be taken before interpreting between-group differences of ERP components. First, between-group comparisons have to take into account differences in sample size. Although a split in two groups with 6 and 8 subjects each seems to be reasonable on the basis of the RT distribution (cf. Figure 2), this procedure requires caution in the interpretation of between-group differences of ERP components. In fact, the smaller ERP components for the slow comprehension group ($n = 8$) might reflect more interindividual variance in the latency and amplitude of ERP components, yielding reduced ERP components in this group. To examine to what extent differences in sample size might have affected the ERP amplitudes in both of the groups, we compared variability scores (*SD*s) for the N400 and P345 components in both of the groups at the Cz and Pz electrodes, respectively. For N400, *SD*s were 2.6 for the slow group and 1.6 for the fast group. For P345, the corresponding values were 4.32 and 5.34. This pattern of results suggests that at least for P345 the interindividual variance was not larger in the slow group than in the fast group. Second, given the large between-subject variability in the magnitude of ERPs, it is also conceivable that absolute ERP amplitudes can vary between groups for reasons unrelated to processing factors. Thus the reduced P345 components in the slow comprehender group could have resulted from the fact that the ERPs in the slow group were in general attenuated rather than bearing any functional significance. If this were the case, we would expect all ERP components in the slow group to have been attenuated relative to the components in the fast group. Examination of Figure 3, however, reveals that the negativity preceding the auxiliary was larger in amplitude for the slow group than for the fast group. This observation suggests that the between-group differences in ERP components very likely did not result from a general attenuation of the slow groups' ERP components.

APPENDIX
The 32 Quartets Including the Two Nouns and the Past Participles of the Neutral and the Semantically Biased Verbs

Noun 1	Noun 2	Biased Verb	Unbiased Verb
Bürgerin (citizen)	Politikerin (politician)	gewählt (elect)	gegrüßt (greet)
Mörderin (murderer)	Passantin (passer by)	angeschossen (shoot at)	angehalten (stop)
Psychologin (psychologist)	Bewerberin (applicant)	getestet (test)	gesehen (see)
Zuschauerin (spectators)	Läuferin (runner)	angefeuert (incite)	angelächelt (smile at)
Professorin (professor)	Studentin (student)	geprüft (examine)	gesucht (seek)
Redakteurin (editor)	Abonnentin (subscriber)	angeworben (hire)	angerempelt (bump into)
Löwin (lioness)	Gazelle (gazelle)	gerissen (attack)	gewittert (smell)
Schneiderin (tailoress)	Freundin (friend)	eingekleidet (fit out)	eingeschüchtert (intimidate)
Trainerin (trainer)	Schwimmerin (swimmer)	gefördert (promote)	getroffen (meet)
Pilotin (pilot)	Diplomatin (diplomat)	eingeflogen (fly in)	eingeladen (invite)
Pflegerin (nurse)	Patientin (patient)	gewaschen (wash)	gesprochen (talk to)
Ausbilderin (instructor)	Helferin (assistant)	angelernt (acquire by study)	angezeigt (report to the police)
Künstlerin (artist)	Urlauberin (holiday-maker)	gemalt (paint)	gestört (disturb)
Hausfrau (housewife)	Vertreterin (representative)	abgewimmelt (get rid of)	abgelenkt (distract)
Fahnderin (police-inspector)	Schmugglerin (smuggler)	gefaßt (capture)	gewarnt (warn)
Detektivin	Bankräuberin	aufgespürt	angeblickt

APPENDIX (Continued)

Noun 1	Noun 2	Biased Verb	Unbiased Verb
(detective)	(robber)	(find)	(look at)
Siegerin	Verliererin	getröstet	gemieden
(winner)	(looser)	(console)	(avoid)
Quizmasterin	Kanditatin	angekündigt	angerufen
(quizmaster)	(candidate)	(announce)	(call)
Katze	Maus	gejagt	geweckt
(cat)	(mouse)	(chase)	(wake up)
Polizistin	Diebin	abgeführt	angegrinst
(police woman)	(thief)	(lead away)	(smile at)
Therapeutin	Alkoholikerin	geheilt	gekannt
(therapist)	(alcoholic)	(cure)	(know)
Fotografin	Braut	abgelichtet	aufgesucht
(photographer)	(bride)	(take a picture)	(seek out)
Hündin	Touristin	gebissen	gemocht
(she-dog)	(tourist)	(bite)	(like)
Stewardess	Passagierin	angeschnallt	angestarrt
(stewardess)	(passenger)	(fasten one's safety belt)	(gaze at)
Lehrerin	Schülerin	getadelt	geachtet
(teacher)	(pupil)	(blame)	(respect)
Fabrikantin	Arbeiterin	ausgebeutet	aufgeregt
(factory owner)	(worker)	(exploit)	(excite)
Kamerafrau	Demonstrantin	gefilmt	gehaßt
(camera woman)	(demonstrator)	(film)	(hate)
Spionin	Ministerin	abgehört	aufgeschreckt
(spy)	(minister)	(overhear)	(startle)
Entführerin	Millionärin	geknebelt	gemustert
(kidnapper)	(millionaire)	(gag)	(examine)
Fürsorgerin	Asylantin	aufgenommen	angesprochen
(welfare worker)	(refugee)	(pick up)	(speak to)
Graphikerin	Sängerin	gezeichnet	gefunden
(graphic artist)	(singer)	(draw)	(find)
Gastgeberin	Nachbarin	ausgeladen	ausgelacht
(hostess)	(neighbor)	(put off)	(deride)

Note—English translations (in parentheses) are approximations, as for some of the transitive verbs there are no English equivalents. All nouns have feminine gender, in most cases indicated by the suffix *-in*.

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