Processing a second language: late learners' comprehension mechanisms as revealed by event-related brain potentials*

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Sentence comprehension in second language (L2) learners was examined using event-related brain potentials (ERPs). Native Japanese speakers who had learned German as a second language after puberty listened to German sentences which were either correct, semantically incorrect, syntactically incorrect or both semantically and syntactically incorrect. Brain responses were registered while participants listened to these sentences. Grammaticality judgments required after each sentence revealed that their overall performance was not perfect but clearly above chance. When comparing the L2-learners' brain responses to those of native listeners, a variety of differences were observed. Whereas semantically incorrect sentences showed an ERP pattern similar to that of native listeners (a centro-parietal N400-effect), correct sentences elicited a greater positivity in L2-learners than in native listeners, possibly in reflection of greater difficulties in syntactic integration. For sentences containing a phrase structure violation, L2-learners did not show significant modulations of the syntax-related ERP components usually seen in native listeners (i.e. the early anterior negativity and the P600). Furthermore, sentences containing a pure semantic or a combined syntactic and semantic violation elicited a late right anterior-central negativity, an effect which has not been observed for native language processing. The topography of the effect may suggest that these additional processes are based on conceptual-semantic rather than on lexical-semantic aspects.

Learning a second language and using it efficiently become more difficult with increasing age. There are a large number of behavioral studies indicating that, in contrast to lexical-semantic aspects, syntactic and phonological aspects of a second language are particularly hard to master during late acquisition (for an overview see De Groot and Kroll, 1997; Ritchie and Bhatia, 1996)

Neurophysiological studies, though less numerous, provide additional evidence for the view that the age at the time of L2-acquisition is critical for the mastery of that language and, moreover, for the functional specialization of language in the brain (Neville, Mills and Lawson, 1992; Neville, Coffey, Lawson, Fischer, Emmorey and Bellugi, 1997; Weber-Fox and Neville, 1996). Weber-Fox and Neville (1996) investigated bilinguals who were exposed to their L2 at different points in development. The processing of semantic aspects was affected only in participants who had learned the second language after puberty. The processing of syntactic aspects, in contrast, deviated from the normal brain activity pattern in all but those participants who were exposed to the second language before the age of four. These data have been taken as support for the view that there is a critical period for language learning during postnatal maturation (cf. Lenneberg, 1967; Harley and Wang, 1997; Johnson and Newport, 1989). At the very least, these data suggest that differential brain mechanisms may be involved for syntactic processing in late language learners as compared to native speakers and early language learners. Recent brain imaging studies investigating sentence processing seem to indicate that this is indeed the case (Dehaene et al., 1997; Kim, Relkin, Lee and Hirsch, 1997; Perani et al., 1996). It was reported that brain activation for L1 and L2 use show only little overlap in late bilinguals (but see Klein, Milner, Zatorre, Zhao and Nikelski, 1999, who argue for a shared neural substrate). A recent study by Perani et al. (1998) suggests that the attained proficiency level in L2 rather than age of acquisition determines the amount of overlap of the cortical representation of L1 and L2.

The particular brain mechanisms underlying language comprehension in less proficient language

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users who appear to have incomplete syntactic knowledge but comprehend most utterances during normal conversation remain to be uncovered. As there are different electrophysiological markers for the processing of specific types of information, such as lexical-semantic and syntactic information, during sentence comprehension, the use of these methods may help to determine the specific processing characteristics in these L2-learners.

Electrophysiological markers of language processes

The registration of event-related brain potentials (ERPs) allows us to differentiate lexical-semantic from syntactic processes. ERPs recorded from the scalp are small voltage changes in the electroencephalogram (EEG) reflecting the summation of synchronous post-synaptic activity of a large population of neurons. ERPs are extracted from the EEG by averaging the signal time-locked to stimulus presentation. An ERP consists of positive and negative voltage peaks which are referred to as *components*. These components vary in polarity, latency and in scalp distribution (cf. Coles and Rugg, 1995; Rugg and Coles, 1995). Modulations in the amplitude or the latency of a component as a function of experimental manipulation are referred to as ERP-effects. Such quantitatively different ERP patterns are taken to provide evidence for different levels of engagement of the same neural structures and therefore functional processes. By contrast, qualitatively different ERP patterns, i.e. differences in polarity or scalp distribution, are assumed to constitute evidence for the involvement of different neural structures and functional processes. Qualitatively different ERP patterns have been found to correlate with particular aspects of language processing.

Language-related ERPs in native speakers/listeners

Semantic processes in sentence comprehension have been studied extensively following the first report of an ERP correlate provided by Kutas and Hillyard in 1980. The initial study demonstrated that sentences ending in a word which could not be semantically integrated into the prior sentence context (''He spread the warm bread with *socks*''), elicited a waveform in the ERP that was more negative than that for a correct control word. This difference had a centroparietal scalp distribution and reached its maximal activity about 400 ms after the onset of the presentation of the critical sentence-final word; it is therefore called the *N400-effect*. This effect was first reported for visual presentation but has subsequently also been shown for auditory presentation as well as for different languages, including American Sign Language (see Kutas and Van Petten, 1994; Van Petten, 1995 for reviews). The amplitude of the N400 component was shown to be inversely correlated with the word's expectancy (Kutas, Lindamood and Hillyard, 1984), i.e. this component can also be observed in correct sentences. It is assumed that the N400 component reflects processes of lexical-semantic integration (Bentin, Kutas and Hillyard, 1995; Brown and Hagoort, 1993; Chwilla, Brown and Hagoort, 1995; Rugg, 1990).

ERP studies on *syntactic* aspects of sentence comprehension have revealed a more complex pattern. While some studies reported negativities correlated with syntactic processes, others observed a late positivity or a combination of the two effects. The observed negative potential in correlation with syntactic incongruity was often maximal over the left anterior scalp and has therefore been labeled *LAN* (left anterior negativity). The latency of the LAN effect varies across different studies. While these effects are mostly reported in the range of 300 to 500 ms after target onset, some studies report an even earlier negativity with a latency ranging from 100 to 250 ms. This negativity is referred to as early anterior negativity. A modulation in the early anterior negativity has been observed for phrase structure violations or word category violations (Friederici, Pfeifer and Hahne, 1993; Gunter, Friederici and Hahne, 1999; Hahne and Friederici, 1999; Neville, Nicol, Barss, Forster and Garrett, 1991), as well as in correlation with the processing of closed class words as opposed to open class words (Brown, Hagoort and te Keurs, 1999; Neville, Mills and Lawson, 1992; Nobre and McCarthy, 1994). It has been demonstrated to reflect rather automatic processes as it is neither influenced by the proportion of correct and incorrect sentences nor by a differential attentional focus introduced via the task instructions (Hahne and Friederici, 1999, 2000). In contrast to the early anterior negativity, the LAN effect in the time range 300–500 ms has been shown to be elicited by a variety of other syntactic violations, such as for example morphological agreement violations (Coulson, King and Kutas, 1998; Gunter, Stowe and Mulder, 1997; Münte, Matzke and Johannes, 1997; Osterhout and Mobley, 1995; Penke, Weyerts, Gross, Zander, Münte and Clahsen, 1997). From a temporal point of view, the data suggest that information about word class (open versus closed) and word category (e.g., noun versus verb) is processed earlier than, for example, morphosyntactic features.

The second component that has been consistently reported in correlation with syntactic processing is a positive component with a latency of about 600 ms

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and generally a centro-parietal maximum. This is usually referred to as the P600 component (e.g., Osterhout and Holcomb, 1992). Modulations of the P600 amplitude have been observed in a number of contexts: with outright violations of phrase structures, preference violations of phrase structures, syntactic ambiguities in garden-path sentences and morphosyntactic violations (Friederici, Hahne and Mecklinger, 1996; Hagoort, Brown and Groothusen, 1993; Hahne and Friederici, 1999; Mecklinger, Schriefers, Steinhauer and Friederici, 1995; Osterhout and Holcomb, 1992, 1993; Osterhout, Holcomb and Swinney, 1994; Coulson et al., 1998; Gunter et al., 1997; Münte et al., 1997; Osterhout and Mobley, 1995). Recently, Kaan, Harris, Gibson and Holcomb (2000) reported modulations of the P600 amplitude in correlation with different degrees of syntactic complexity.

Current knowledge about the relationship between the different types of syntactic ERP components and the functional processing steps they may reflect is, however, scarce. The P600 has been described as a reflection of "cost of reprocessing" (Osterhout et al., 1994), an "electrophysiological manifestation of parsing" (Hagoort et al., 1993, p. 439) or an "electrophysiological marker of syntactic anomaly" (McKinnon and Osterhout, 1996, p. 517). Given its dependence upon attentional resources (Coulson et al., 1998; Gunter et al., 1997; Hahne and Friederici, 1999) and the latency of the effect (in absolute terms as well as in relative terms when compared to the N400) this component seems to reflect a controlled process. Therefore, it has been questioned whether the P600 should be viewed as a primary reflection of syntactic processing (Coulson et al., 1998; Friederici et al., 1993; 1996; Gunter et al., 1997; Münte et al., 1997). Recent studies of syntax-related ERPs focused on the negative components suggesting that "the LAN may be a more direct index of syntactic processing than the P600" (Coulson et al., 1998, p. 50). Friederici (1995, 1998; Friederici et al., 1996) proposed a three-phase model for sentence comprehension integrating the seemingly heterogeneous results. According to this model the parser first assigns an initial structure on the basis of word category information during the first-pass parse which is reflected in the early anterior negativity. During the second phase lexical-semantic as well as verb argument structure and local agreement information is processed, which are associated with the N400 and the LAN respectively. During the third phase second-pass parse processes take place and a reanalysis or repair, which is reflected in the P600, may be initiated.

Recently, Kaan et al. (2000) interpreted the P600 as "an index of syntactic integration difficulty" (p. 159) as they also observed the P600 effect in grammatical, non-garden-path English sentences relative to a syntactically simpler sentence. Friederici, Hahne and Saddy (in press) also observed the P600 to vary as a function of syntactic complexity and as a function of syntactic repair but, moreover, found topographic differences. Sentences of greater complexity elicited a more frontal positivity than sentences which contained a syntactic violation. These combined data suggest that different types of P600–effects have to be differentiated into processes related to the difficulty of syntactic integration on the one hand, and processes of syntactic repair on the other hand.

Language-related ERPs in bilinguals

There are only a few studies on bilinguals' language processing using ERP measures. Investigating semantic aspects of language processing, Ardal, Donald, Meuter, Muldrew and Luce (1990) found the latency of the N400-effect to semantic anomalies to be delayed in fluent bilinguals compared to monolinguals as well as in L2 compared to L1 within the bilingual group. Kutas and Kluender (1991) also reported a delay of the N400 latency in the bilinguals' less fluent language, in addition to an amplitude reduction of the N400-effect. Weber-Fox and Neville (1996) examined semantic and syntactic aspects of processing as a function of age-of-exposure to L2 in five different groups (1–3, 4–6, 7–10, 11–13, after 16 years). Participants performed an acceptability judgment task. They found the N400 to be present in all groups, but delayed in those who learned L2 after 11–13 years. For phrase structure violations, monolinguals showed differential effects for an early left anterior negativity (N125) and a second left lateralized negativity (N300–500) that were followed by a P600-effect (P500–700). None of the bilingual groups displayed an early left anterior negativity (N125). Late learning bilinguals (11–13 and >16) showed an early negativity, though with a bilateral distribution. In the 300–500 ms time window a negative effect was found for all groups, which was left lateralized for early learners (1–3, 4–6, 7–10) but more bilaterally distributed for late learners (11–13, >16). The P600-effect was also present in early learners (1–3, 4–6, 7–10), but not in the late learners.

From these studies it appears that semantic processes are slowed down in late L2–learners and that syntactic processes are qualitatively different when L2 is learned after the age of 11–13. Late L2-learners not only displayed a more bilateral ERP pattern for the syntax-related negativity (N300–500), but also

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the absence of a modulation of the P600 (P500–700), which has been interpreted to reflect processes of syntactic reanalysis and repair (Friederici, 1995). This seems to suggest that these late syntactic processes are different in late L2-learners.

The present study

The present study used ERP measures to investigate the processing mechanisms underlying late L2-learners' comprehension of auditorily presented sentences. The design of the experiment was adopted from a study with native listeners (Hahne and Friederici, 1998, 2000). Four different types of sentences were used.

(1) correct	Das Brot wurde *gegessen*. (The bread was eaten)
(2) semantically incorrect	Der Vulkan wurde *gegessen*. (The volcano was eaten)
(3) syntactically incorrect	Das Eis wurde im *gegessen*. (The ice cream was in-the eaten)
(4) semantically and syntactically incorrect	Das Türschloss wurde im *gegessen*. (The door lock was in-the eaten)

In the semantic condition (2), the selectional restriction information of the verb is not compatible with the preceding sentence context. In the study using the same sentences in native listeners, we found an N400 effect for the critical sentence-final word in this semantically incorrect condition. In the syntactic condition (3), the phrase structure of the sentence was violated. The preposition requires a noun phrase and not a verb as a correct continuation. In the L1-group, this condition elicited a modulation of the early anterior negativity followed by a P600 effect. The ERP pattern for the combined violation condition (4) was similar to that of condition (3), i.e. modulations of the early anterior negativity and the P600, but no N400 component. Given that the N400 is taken to reflect lexical-semantic integration processes, the absence of an N400 in condition (4) indicates that lexical-semantic integration does not take place when the lexical targets' word category is incompatible with the prior syntactic context. It appears that the early detection of a syntactic violation as indicated by the early anterior negativity can block lexical-semantic integration (Hahne and Friederici, 1998, 2000). This effect was also observed in a study using visual stimulus presentation (Friederici, Steinhauer and Frisch, 1999). Interestingly, this blocking effect can be overcome by the nature of the task. If participants were instructed to ignore syntactic violations and concentrate on the semantic matching of the verb's selectional restrictions and the preceding noun, these sentences elicited an N400 effect in addition to a differential early anterior negativity (Hahne and Friederici, 1998, 2000). This indicates that the process reflected in the N400 component is rather controlled as its elicitation depends on attention. Furthermore, the presence of a modulation of the early anterior negativity despite the instruction to ignore syntactic violations further supports the idea that the underlying process can best be characterized as rather automatic.

Sentences of types (1–4) were presented to Japanese native speakers who had learned German as L2 after puberty. Based on the general finding from behavioral studies that lexical-semantic information is acquired more easily than syntactic information during late acquisition, we expected the ERP pattern for these participants to differ from those of native listeners, particularly for sentences containing a syntactic violation (3 and 4). Recall that the early anterior negativity is taken to reflect highly automatic first-pass parsing processes and that the P600 is interpreted to reflect secondary syntactic processes of reanalysis and repair. If L2-learners process their second language in a non-automatic manner (e.g. Vaid, 1983; Favreau and Segalowitz, 1983; Segalowitz, 1986), we predict the absence of a modulation of the early anterior negativity for the syntactically incorrect condition. A P600 effect may be present in case syntactically driven repair processes are available, if not, the P600 effect should also be absent. For the semantically incorrect condition we predicted an N400 effect (Ardal et al., 1990; Weber-Fox and Neville, 1996).

Method

Participants

Twelve native right-handed speakers of Japanese (mean age 27, range 21–33; 7 female) participated in the study. They were students at the University of Leipzig and had been living in Germany for 29 months on average (median 20, range 2–78). The participants had learned German in formal settings for 30 months (median 29, range 4–60). They started learning German at a mean age of 21 (median 19, range 18–31), i.e. they can all be classified as late learners. At the time of testing they reported that German was their most frequently used language (mean: 64% of the time as opposed to 28% L1). Participants' proficiency self-ratings in German revealed an average value of 3.5 on a six-point scale (1 = no knowledge; 6 = equivalent to native speaker) with hardly any difference between comprehension and production (speaking: 3.4; writing: 3.4; listening: 3.5; reading: 3.5). In addition to German, all partici-

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pants had some knowledge of English (with 95 months of study and a proficiency self-rating of 3.2). They had no known hearing deficits and were paid for their participation.

Materials

The stimulus material was identical to that of a previous study with native listeners (Hahne and Friederici, 1998, 2000). We used one hundred German participles all beginning with the participle marker *ge-*. For each participle, four different sentence beginnings according to the four conditions described earlier were constructed. All sentences were in the passive voice. In the semantic condition, the selectional restrictions of the verb were violated. In the syntactic condition, the participle directly followed a preposition. As the preposition requires a noun phrase to follow before it allows for a verb, this sequence creates a phrase structure violation. All prepositions used in the experiment were merged forms consisting of a preposition and a determiner (as, for example, *im* = *in dem* (*in the*)). In addition, sentences containing a complete prepositional phrase (preposition plus noun = correct filler condition: *Die Pizza wurde im Restaurant gegessen (The pizza was in-the restaurant eaten)*) were created for each of the hundred participles in order to prevent anticipation of the syntactic violation on the preposition, thus resulting in five hundred experimental sentences. Each participant received two hundred of these sentences, 40 in each of the five conditions. The same participle was presented twice per participant but in different conditions. The sampling of these two sentences out of the set of five sentences was systematically varied and counterbalanced over subsets of items and subgroups of participants, such that each participle contributed to each experimental condition equally often and each participant received items from all experimental conditions equally often. Furthermore, to establish an approximately equal number of correct and incorrect sentences and to approximately equate the probability of the transitions "auxiliary → participle" versus "auxiliary → preposition" on the one hand and "preposition → noun" versus "preposition → participle" on the other hand, we included 40 additional filler sentences. Twenty of these were presented in the correct condition, ten in the correct filler condition and ten in the semantic condition. These filler sentences were presented to each participant resulting in an overall percentage of 46% correct sentences and 54% incorrect sentences. Of all these, 46% contained an auxiliary–participle transition and 54% contained an auxiliary–preposition transition. Five experimental lists were created with 240 items each. These 5 lists were individually pseudo-randomized ensuring that not more than 3 sentences of one condition and not more than 4 correct versus incorrect sentences appeared in succession and that at least 30 trials separated the repetition of the same participle. The 5 lists were presented forward and backward resulting in 10 different presentation lists which were all presented at least once.

Sentences were 16-bit digital sound files sampled at 22 kHz and spoken by a female native speaker of German. To prevent differences with regard to prosodic parameters in the two conditions containing phrase structure violations which might occur in the production of syntactically incorrect sentences, the speaker originally produced sentences containing a complete prepositional phrase in these conditions (cf. Hahne and Friederici, 1999, 2000). This extra noun was later excised from the digital speech file. To ensure that this procedure would not lead to any audible splicing artifacts, the additional noun always had the same onset-phoneme as the participle and ended in a phoneme which was identical to the last phoneme of the preposition occurring in that sentence.[1]

Procedure

Participants were seated in a comfortable chair about 0.9 m in front of a computer monitor. They were separated from the experimenter by a partition-wall. Prior to the experiment, five practice trials were given containing similar items not used in the experiment proper. The 240 items were then presented with rest breaks after every 48 trials. The trial structure was as follows. A fixation point was presented on the CRT screen 500 ms before the auditory sentence presentation started and remained on the screen until 3,000 ms after the end of the auditory presentation. Then a response sign appeared on the screen for 1,500 ms. This delayed response was used to avoid an overlap of language-related ERP-components with movement-related components. The next trial began after an inter-trial-interval of 1,500 ms. Sentences were presented via loudspeakers. Participants were instructed to minimize eye and body movements

[1] Concerns may be raised that this procedure still resulted in perceptible splicing artifacts. However, a perceptual study showed that native German listeners were not able to differentiate between sentences containing a splice and the same sentences produced naturally. Furthermore, the overwhelming majority of the sentences was rated as "sounding natural" (see Hahne and Friederici, 2000, for a detailed description of the auditory sentence materials and a further discussion of prosodic influences on the ERP-effects in native listeners).

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during the presentation of the fixation star and to judge the sentences for linguistic integrity by pressing one of two buttons during the presentation of the response signal. The instructions did not differentiate between the different types of errors and included one example sentence of each of the five sentence types. Following the ERP session participants completed a language history questionnaire.

ERP recording and data analysis

The EEG was recorded with AgAgCl electrodes mounted in an elastic cap from 25 scalp sites (FP1/2, F7/8, F3/4, FT7/8, FC3/4, T7/8, C3/4, CP5/6, P7/8, P3/4, O1/2, Fz, Cz, Pz; nomenclature based on Sharbrough, Chatrian, Lesser, Lüders, Nuwer, and Picton, 1991). The vertical electro-oculogram (EOGV) was recorded from a bipolar electrode pair situated above and below the right eye and the horizontal EOG (EOGH) was recorded from a bipolar electrode pair located at the outer canthus of each eye. Electrode impedance was kept below 3 kΩ. All scalp electrodes were referenced to the left mastoid. The right mastoid was actively recorded and the data were re-referenced to the algebraic sum of the left and the right mastoids off-line. Band pass was set from DC to 70 Hz, and the digitization rate was 250 Hz. Off-line, all trials were examined for excessive EOG amplitude. An epoch was rejected whenever the standard deviation for a 200 ms moving window exceeded 40 μV in the EOG channels. Additionally all trials were inspected by the experimenter and trials contaminated with artifacts were rejected. ERPs were extracted by averaging single trials separately for participants, electrodes and experimental conditions for 1500 ms after the onset of the participle relative to a 100 ms post-stimulus-onset baseline. Only correctly answered trials were included in the averaging procedure. The mean number of trials which entered the average after elimination of trials contaminated by artifacts and incorrectly answered trials was 31 for the correct condition, 33 for the semantic condition, 24 for the syntactic condition and 35 for the combined condition.

Averaged error rates and reaction times were submitted to multivariate analyses of variance with the within-participant variable condition (correct, semantic, syntactic, combined). Statistical evaluation of the ERP data was three-fold. First, we analyzed average voltage amplitudes in defined time windows relative to the onset of the participle. The following time windows were quantified: 100–250 ms for the early anterior negativity usually observed for syntactic violations in native listeners; 400–700 ms for the N400 component and 700–1100 ms for the late right frontal negativity observed in the semantic and in the combined condition as well as for the small negativity observed in the syntactic condition. The selection of these time windows was based on a visual inspection of the grand average and on the latency of these components in previous studies using auditory presentation in native listeners. Repeated measure ANOVAS were performed with three within-subject variables for the lateral electrodes: condition (correct vs. incorrect), hemisphere (left vs. right) and region (anterior vs. central vs. posterior). The variables hemisphere and region were completely crossed, yielding six regions of interest containing three electrodes each: left anterior (F7, F3, FT7), right anterior (F8, F4, FT8), left central (T7, C3, CP5), right central (T8, C4, CP6), left posterior (P7, P3, O1) and right posterior (P8, P4, O2). Whenever an interaction between the variable condition and a topographic variable reached a significance level of $< .10$, subsequent analyses were performed.

Second, we analyzed 30 intervals of 50 ms length for each electrode, as this procedure allows for a detailed evaluation of onset and duration parameters (see Gunter et al., 1997; Gunter, Friederici and Schriefers, 2000, for a similar procedure). This procedure seemed to be appropriate for the present data as onset and duration of effects are of particular interest. Furthermore, as there are no previous studies examining similar effects in L2-learners, the chosen time windows cannot be based on previous results in the literature. Analyses of variances were computed for the three incorrect conditions relative to the correct condition for each electrode position separately. In order to minimize type 1 errors, significance of an effect will be assumed whenever two or more successive interval-analyses reached a significance-level of $< .05$. These data are presented in Figure 6.

Third, we conducted direct comparisons between the present study (testing L2-learners) and a previous study testing 16 German native speakers (mean age 25 years, range 19–35) with the same stimulus materials (Hahne and Friederici, 1998, 2000). The two studies were highly comparable with respect to methodological aspects. One difference between the two studies was that the L1-study used only 16 lateral EEG electrodes. Therefore all analyses comparing the two groups involved only four regions of interest with four electrodes each: left anterior (F7, F3, FT7, FC3), right anterior (F4, F8, FC4, FT8), left posterior (CP5, P7, P3, O1) and right posterior (CP6, P8, P4, O2). Group (L1 vs. L2) was treated as a between-subject factor. The Greenhouse-Geisser correction was applied whenever effects with more than one degree of freedom in the numerator were evaluated

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(Greenhouse and Geisser, 1959). Below, we report uncorrected degrees of freedom and corrected probabilities.

Results

Behavioral data

The error rates of L2–learners in the grammaticality judgment were clearly above chance in all conditions, suggesting the presence of some knowledge of German (correct condition: 22.3%, semantic condition: 18.3%, syntactic condition: 33.1%, combined condition: 14.0%). A MANOVA revealed a main effect of condition ($F(3,9) = 5.24$, $p < .023$). A Newman-Keuls test showed that participants made more errors in the syntactic condition than in the three other conditions. Still, the performance in the syntactic condition differed significantly from chance level ($t(11) = 3.52$, $p < .01$). The fact that performance was much higher in the combined than in the syntactic condition may suggest that late L2-learners processed sentences mainly on the basis of semantic aspects.

As the judgment was given 1500 ms after the offset of the sentences, mean reaction times cannot be considered as an on-line measure of sentence comprehension and they did not, indeed, differ significantly across conditions ($F(3,9) = 1.69$, $p < .24$).

ERP data

The ERP results for the late L2-learners in this experiment exhibited some similarities to those observed in native listeners but also showed some remarkable differences to these (see Figures 1–5).

For sentences containing a *semantic* violation, the ERPs of the L2-group displayed a centro-parietal N400 effect relative to the correct condition. This effect was similar to that shown by native listeners and started particularly early at some outer right electrode sites. Unlike native listeners, however, there was an additional negative effect over right anterior sites. For sentences containing a *syntactic* violation, the L2-group showed hardly any differences in comparison to the correct condition. This is in clear contrast to the findings for native German listeners, who displayed a modulation of an early anterior negativity followed by a P600 effect in this condition. Sentences containing both a *semantic* and a *syntactic* violation showed a right anterior-central negativity similar to the semantic condition while there were no other modulations compared to the correct condition. The data pattern in the combined condition also clearly differs from the native listeners' pattern, which displayed modulations of the early anterior negativity but no N400-effect.

A direct comparison across groups reveals that there are remarkable differences with regard to the processing of correct sentences (cf. Figure 5). In L2-learners, these sentences elicited a large positivity which was widely distributed and more pronounced over the right than over the left hemisphere. For native listeners, a positive waveform was observable only over centro-parietal sites and it was much smaller than in L2-learners. Furthermore, the L2 group showed a small negativity at left anterior electrodes which was not present for the L1 group. In sum, the data comparing the two correct conditions across groups bears some similarities to a comparison of a syntactically incorrect and a correct condition within native listeners. This may suggest that the processes which L2-learners have to conduct in order to understand a correct sentence resembles those performed by native listeners during the processing of syntactically incorrect sentences. Statistical analyses basically supported the descriptive findings.

Semantic condition

Semantic violations showed a significant N400-effect in the analyses of the time window from 400 to 700 ms. The effect was bilaterally distributed over posterior sites and also present over the anterior and central regions of the right hemisphere (Tables 1 and 2). The 50 ms-stepwise analysis supported this observation and showed that, over the right hemisphere, the effect started particularly early at the three outer right electrode sites (F8, FT8 and CP6). A direct comparison between the L2–group and native listeners did not reveal significant differences with regard to the N400-effect (Table 4).

The presence of a right anterior-central negativity in the late time window (700–1100 ms) was confirmed by the statistical analyses. Whereas the right anterior and central regions revealed significant effects of condition, the corresponding left regions did not.[2] In addition, a condition effect was observed for both posterior regions (Tables 1 and 2).

The right anterior-central negativity was not observed in German native listeners. A direct

[2] A corresponding right anterior condition effect is also visible in the EOGH and opens up the possibility that the EEG-effect might be due to eye-movements superimposed on the EEG. However, for the analyzed time window 700–1100 ms the amplitude difference between F8 and F7 is −2.76 μV whereas the EOGH amplitude is only −1.62 μV. This difference shows that the EEG-effect spilled over to the EOG and rules out any artifacts. The same was true for the combined condition (difference between F8 and F7: −1.80 μV; EOGH: −0.99 μV).

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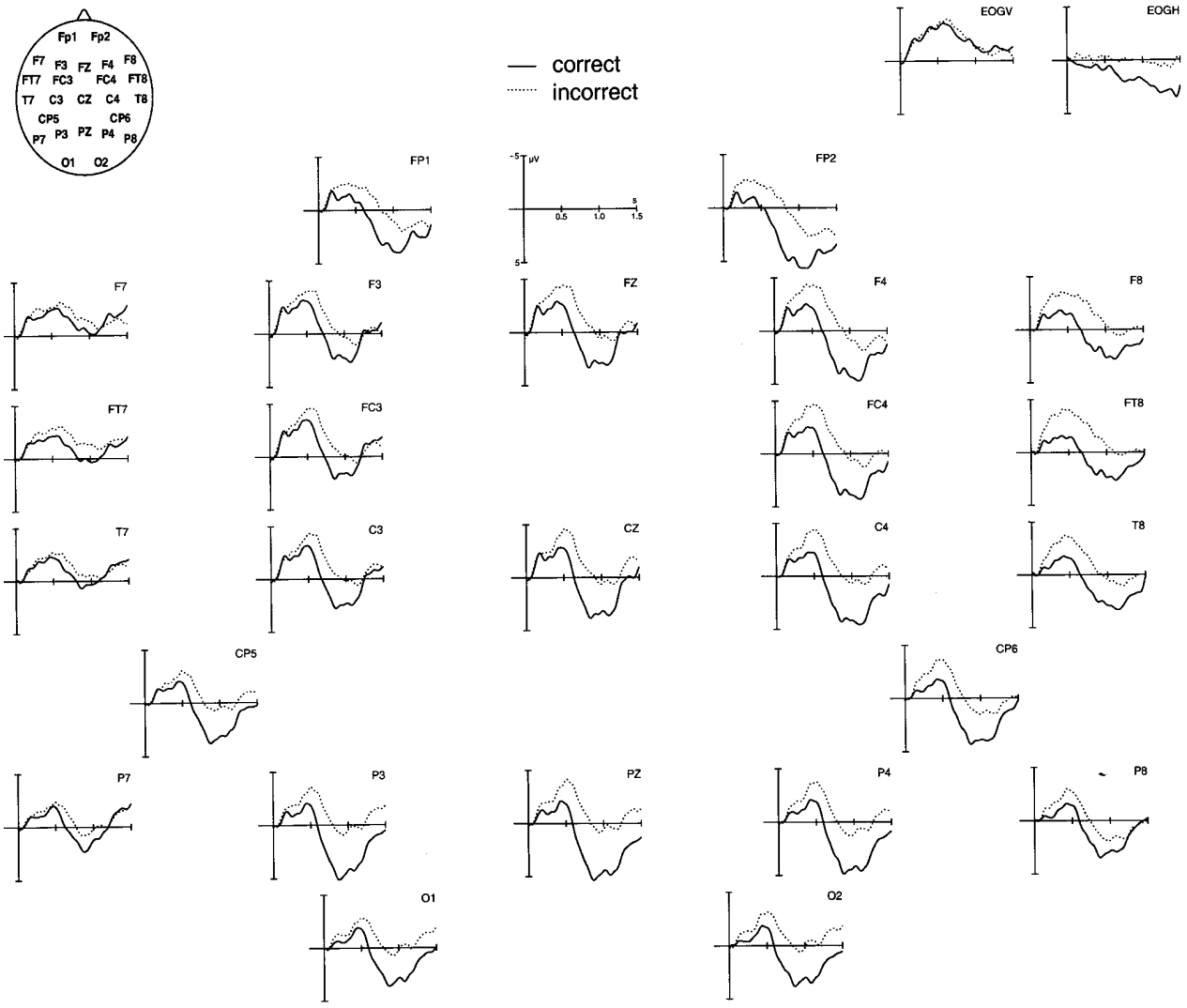


Figure 1. Grand average ERPs for the 25 electrode positions in the semantic violation condition as compared to the correct condition. In this and the following figures, the origin of the x-axis corresponds to the onset of the critical participle and negative voltage is plotted up.

comparison revealed a significant main effect of the variable group as well as an interaction between group and hemisphere (Table 4). Separate analyses for the two hemispheres showed that the two groups differed over the right hemisphere ($F(1,26) = 9.65$, $p < .001$), whereas the effect over the left hemisphere was only marginal ($F(1,26) = 3.78$, $p < .10$).

Syntactic condition

Pure syntactic violations elicited an ERP-pattern very similar to that elicited by correct sentences. Whereas this condition elicited a modulation of an anterior negativity between 100 and 250 ms in native listeners, there is no differential effect observable in the L2-group. An analysis of this early time window did not reveal any significant effects (Table 1 and Figure 6).[3] These clear differences between groups were also supported by the between-subject analyses. Significant group effects were observed for the anterior but not for the posterior electrode positions. These were more pronounced over the left than over the right hemisphere (Tables 4 and 5).

Although the descriptive differences between the correct and the syntactically incorrect condition are very small, there seemed to be a tendency towards a right anterior negativity and a reverse "P600-effect" in the late time window (700–1100 ms). However, statistical analyses showed that none of these effects

[3] The difference did not even reach significance at electrode F7 ($F(1,26) = 1.59$, $p < .22$) on which the descriptive effect was most pronounced.

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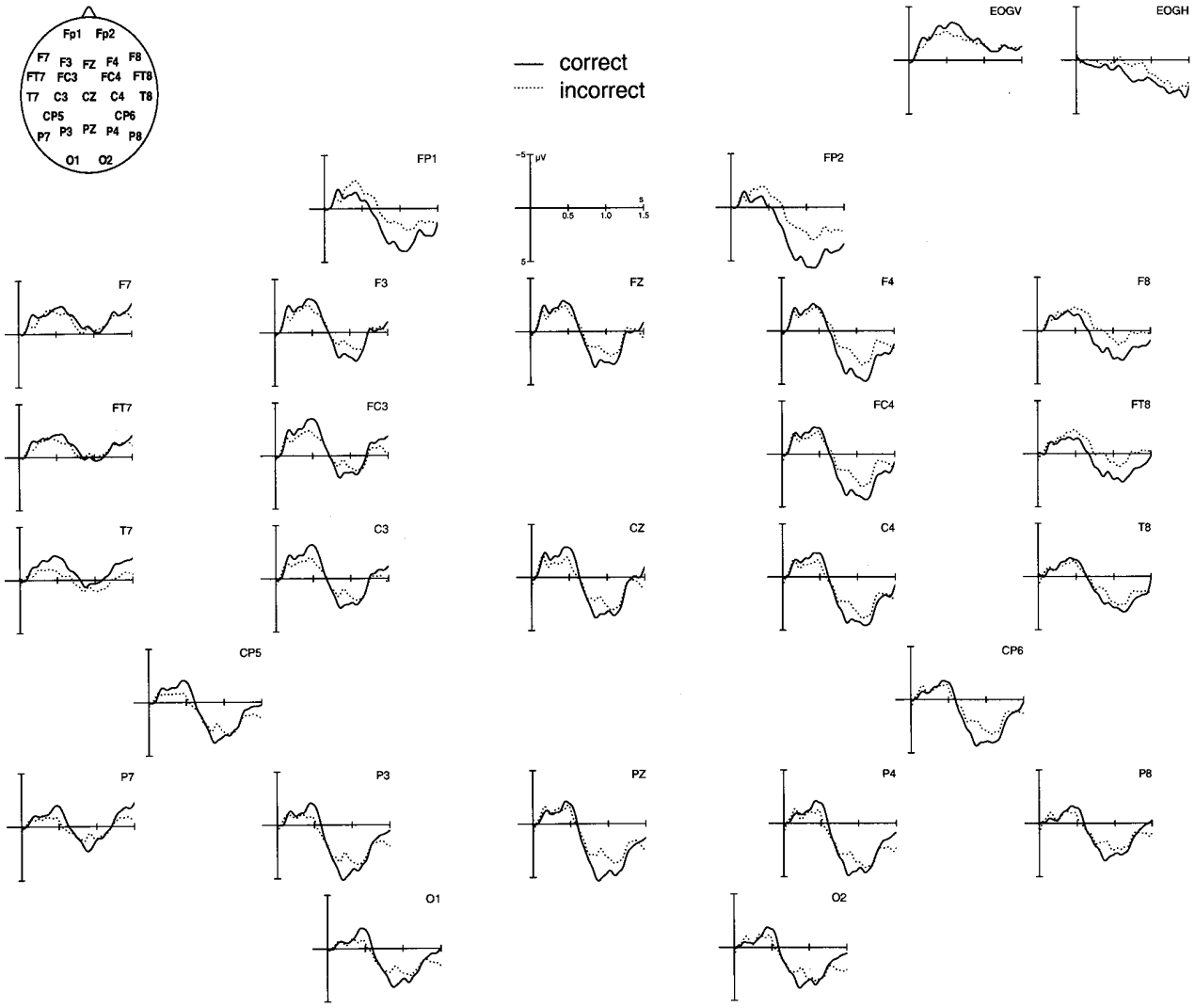


Figure 2. Grand average ERPs for the syntactic violation condition as compared to the correct condition.

reached significance (Table 2). This conclusion is also supported by the 50 ms-step analyses which revealed hardly any systematic and reliable effects (Figure 6).

In order to compare the syntactic effects in the late time window across groups, we analyzed two time windows: first, the time window 700–1100 ms which was also used for analyzing the effects in the semantic and the combined condition and second, the time window 500–1000 ms which may be seen as a more "classical" time window for the P600 component. The two time windows revealed very similar results (Tables 4 and 5). For the posterior regions clear differences between the two groups were observed, suggesting a differential P600-effect for the L1 but not for the L2 group. The F-values suggest a larger group-effect for the right than for the left hemisphere.

Combined condition

Similar to the syntactic condition, the combined condition did not reveal any significant differential effects between 100 and 250 ms (Tables 1 and 2). By contrast, there were significant effects of the variable group, especially for the left anterior region (Tables 4 and 5), demonstrating that a difference between correct and incorrect sentences was observable only for the L1 group.

Within the late time window, the combined condition showed highly significant effects for the right anterior and the right central region, whereas all other regions of interest did not reveal significant effects. The across-group comparison showed group differences for right anterior but not for left anterior sites, thus supporting the descriptive observation that a difference between correct and incorrect sentences for right anterior electrode positions was elicited only

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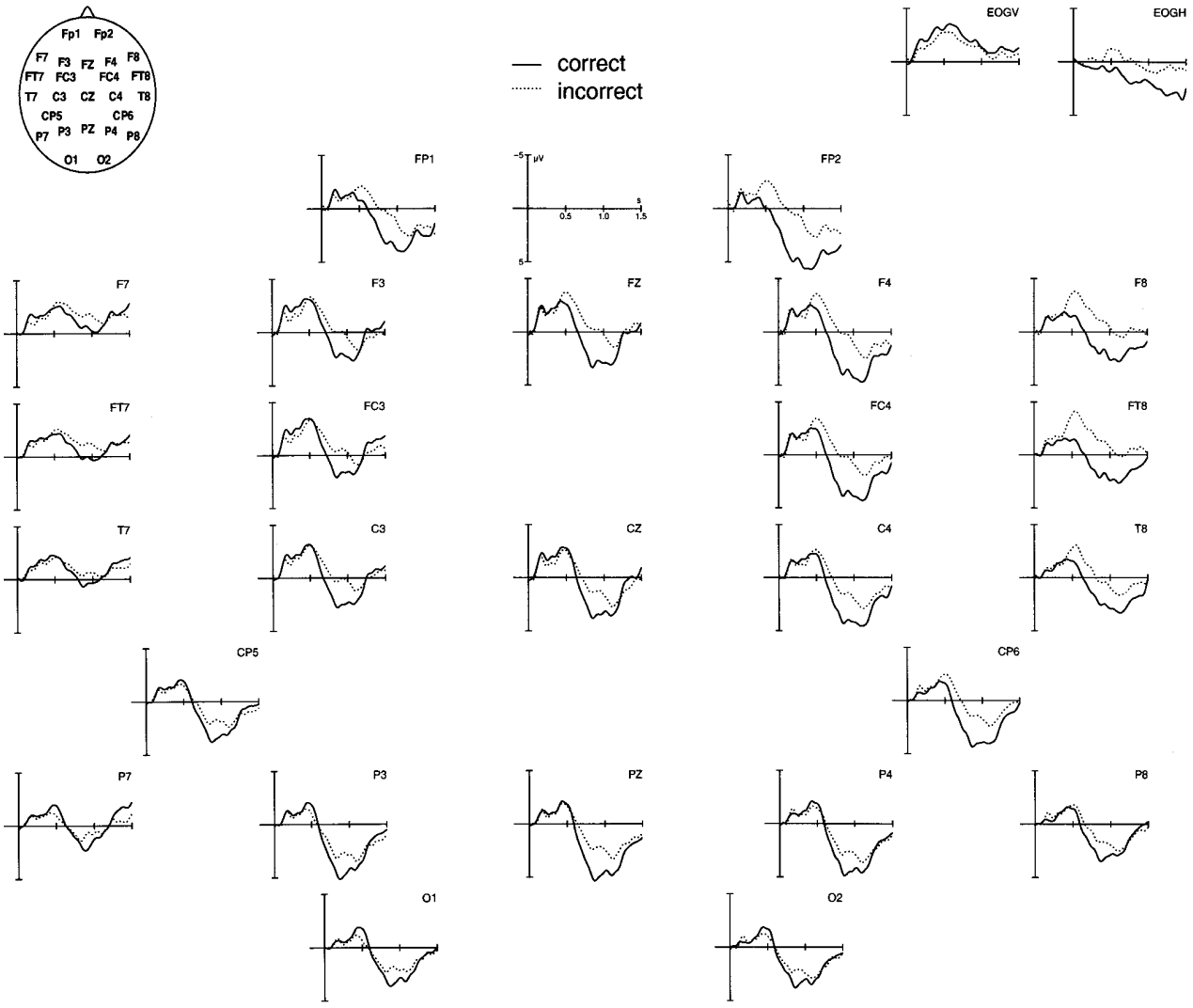


Figure 3. Grand average ERPs for the combined violation condition as compared to the correct condition.

for the second language learners but not for native listeners. In addition, there were significant group effects for the left and right posterior regions, indicating that a differential P600 effect was observable only for the L1 group.

Additional analyses

The N400-effect between 400 and 700 ms appears to be present only for the semantic but not for the combined condition. To test this directly, we conducted analyses for this time window including the variable condition (semantic versus combined). These analyses revealed significant differences for the central and the posterior regions (Tables 1 and 3). Analyses directly comparing the semantic and the combined condition in the late time window (700–1100 ms) only showed significant differences for the posterior but not for the anterior region. A direct comparison between the syntactic and the combined condition for the late time window revealed significant differences only for the anterior and the central but not for the posterior region (Tables 1 and 3). These results demonstrate that the difference between the correct and the incorrect sentences at right anterior sites is similar for the semantic and the combined condition but not for the syntactic condition.

Across-group comparisons for the correct condition

As the ERPs for the correct condition differed descriptively across the two groups, we compared the correct conditions for all the time windows in which the ERP-effects, i.e. differences between incorrect and correct conditions, were analyzed (cf. Figure 5; Tables 6 and 7).

Although there were significant interactions of

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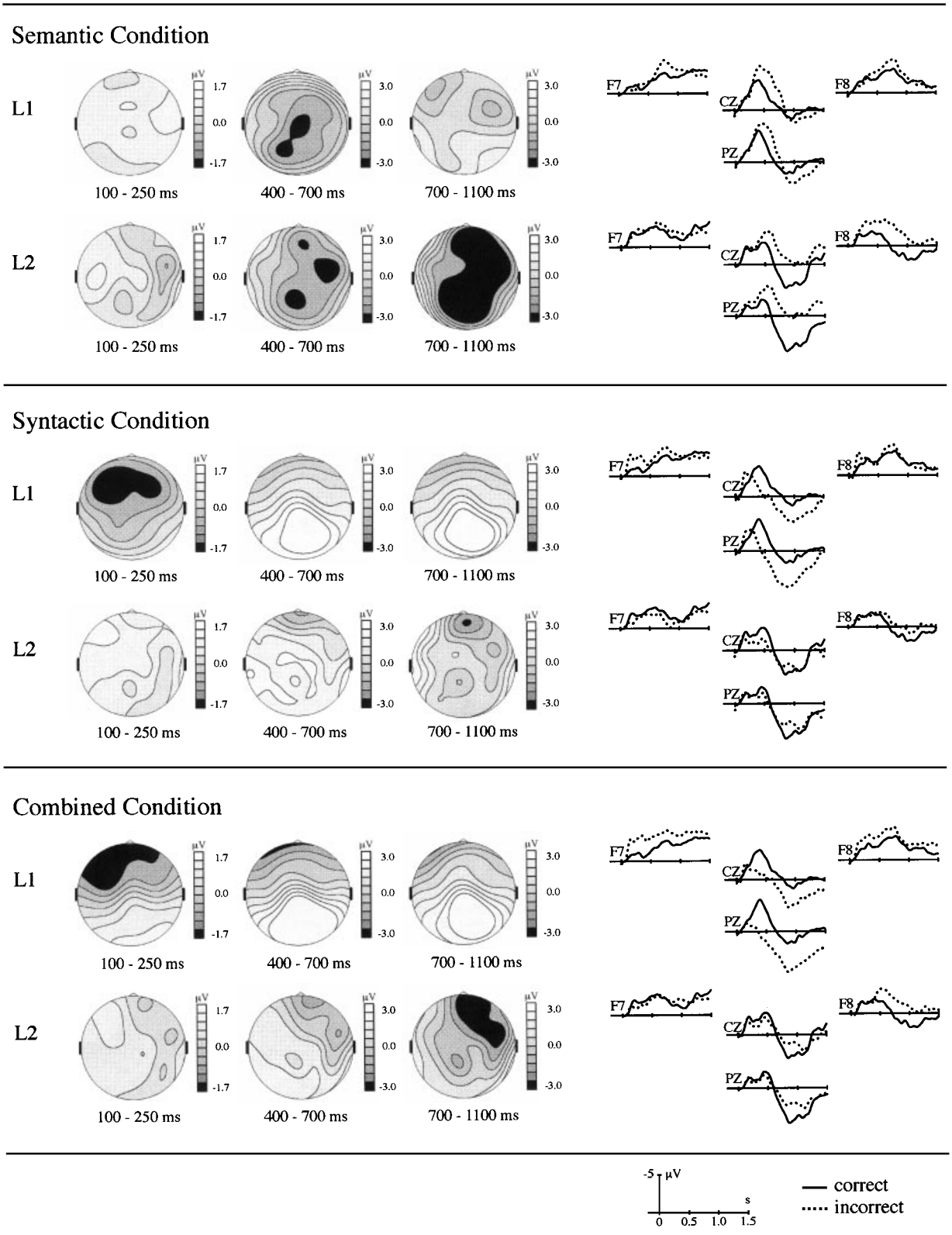


Figure 4. Scalp topography for the differences between ERPs to the three violation conditions and the correct condition and waveforms for selected electrodes for the L2 learners (present experiment: L2) and native listeners processing the same sentences in a previous study (L1: Hahne and Friederici, 2000). All time specifications are relative to the onset of the critical participle.

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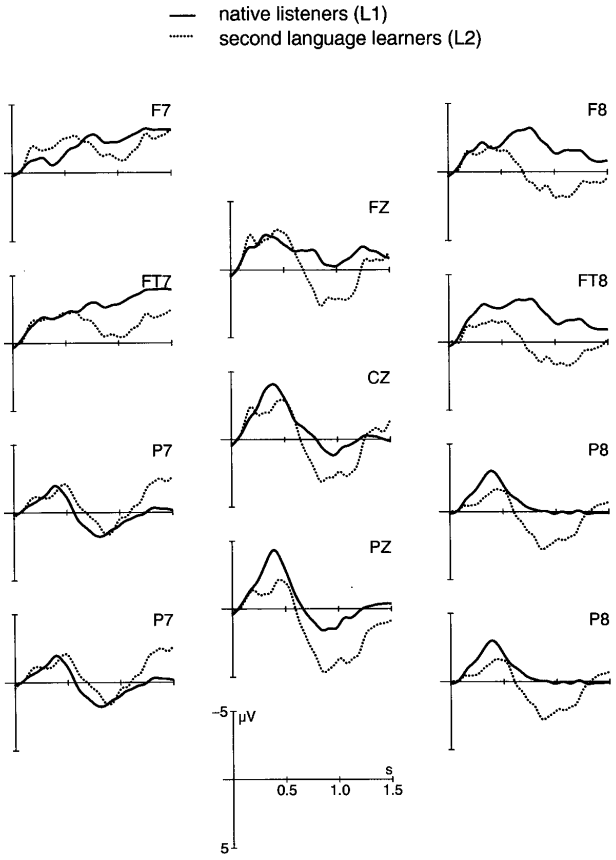


Figure 5. Grand average ERPs for the correct condition for selected electrodes for the L2 learners (present experiment: L2) and native listeners processing the same sentences in a previous study (L1: Hahne and Friederici, 2000). All time specifications are relative to the onset of the critical participle.

group and hemisphere in all time windows, subsequent analyses showed that for the earlier time windows (100–250 ms and 400–700 ms) these were caused by reverse effects which were not significant for each level of the variable hemisphere. Thus, in the time range of the early anterior negativity and the N400 component there were no systematic processing differences with regard to the correct condition across the two groups. By contrast, a significant difference between the groups was observable for the two later time windows (500–1000 ms and 700–1100 ms). Here, correct sentences elicited a more positive ERP in L2 learners than in native listeners.

Discussion

The present experiment investigated the processes underlying the comprehension of spoken sentences in late L2-learners as compared to native listeners. The method of ERPs was chosen for this purpose as it provides differential markers for semantic processes (N400) on the one hand, and for early (early anterior negativity) and late (P600) syntactic processes on the other. The ERPs registered while participants listened to correct and incorrect sentences differed between L2-learners and native listeners as a function of sentence type. We will first discuss the differences between correct sentences across groups and subsequently turn to a discussion of the ERP-effects, i.e. differences between correct and incorrect sentences.

The processing of correct sentences differed significantly across the two groups in the late time range, i.e. the time window in which native listeners usually display P600-effects. L2-learners elicited a much greater positivity than native listeners. The effect was slightly more pronounced over the right than over the left hemisphere and it was observable in anterior as well as in posterior regions. The P600 has been shown to vary in amplitude as a function of syntactic complexity within correct sentences (Kaan et al., 2000) and has thus been interpreted as reflecting processes of syntactic integration difficulty. Friederici

Table 1. *Global analyses of ERP data within the L2 group*

		correct vs. semantic		correct vs. syntactic		correct vs. combined		semantic vs. combined		syntactic vs. combined	
		400–700 ms	700–1100 ms	100–250 ms	700–1100 ms	100–250 ms	700–1100 ms	400–700 ms	700–1100 ms	400–700 ms	700–1100 ms
Source	*df*	*F*	*F*	*F*	*F*	*F*	*F*	*F*	*F*	*F*	*F*
Co	1,11	15.02***	12.72***	< 1	< 1	< 1	6.58**	11.77***	5.22**	4.93**	3.37*
Co x He	2,22	7.45**	9.85***	1.59	4.19*	1.42	7.22**	< 1	< 1	1.83	< 1
Co x Ap	1,11	< 1	< 1	< 1	< 1	< 1	2.24	5.07**	4.02*	1.27	3.02*
Co x He x Ap	2,22	7.03**	8.11***	< 1	4.50**	1.19	3.76*	< 1	< 1	< 1	< 1

Co = Condition; He = Hemisphere; Ap = Anterior–posterior dimension; *p < .10, ** p < .05, *** p < .01

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Table 2. *Analyses of ERP data within the L2 group for each region of interest for those comparisons in which the three-way interaction of condition, hemisphere and ant-pos-dimension reached a significance level of < .10 in the global analyses*

		correct vs. semantic		correct vs. syntactic	correct vs. combined
		400–700 ms	700–1100 ms	700–1100 ms	700–1100 ms
Source	*df*	*F*	*F*	*F*	*F*
Co					
left anterior	1,11	< 1	1.60	< 1	1.19
right anterior	1,11	18.02***	11.75***	1.55	12.00***
left central	1,11	4.05*	5.72**	< 1	2.41
right central	1,11	25.74***	20.47***	< 1	13.32***
left posterior	1,11	7.65**	16.96***	< 1	1.03
right posterior	1,11	13.86***	21.39***	< 1	2.05

Co = Condition; *p < .10, ** p < .05, *** p < .01.

Table 3. *Analyses of ERP data within the L2 group for each of the three levels of the variable anterior–posterior dimension for those comparisons in which the interaction of condition and Ap reached a significance level of < .10 in the global analyses*

		semantic vs. combined		syntactic vs. combined
		400–700 ms	700–1100 ms	700–1100 ms
Source	*df*	*F*	*F*	*F*
Co				
anterior	1,11	1.82	< 1	6.05**
central	1,11	9.33**	3.56*	4.50**
posterior	1,11	33.85***	15.65***	< 1

Co = Condition; *p < .10, ** p < .05, *** p < .01

et al. (in press) also observed a P600-effect for syntactically correct but complex sentences and additionally found different topographic distributions for a P600-effect in a within-subject comparison: whereas syntactically complex sentences elicited a frontal positivity, syntactically incorrect sentences elicited a centro-parietal effect. This suggests that two different subprocesses of the P600 may have to be differentiated. Given these differences in P600-effects for correct sentences in native listeners, it is a very plausible assumption that the differences in amplitude observed for the correct sentences between the two groups reflect an increased difficulty in syntactic integration processes in L2-learners as compared to native listeners. Although the sentences are short, they are in the passive voice and therefore presumably make greater demands upon processing mechanisms in L2 than in L1. The observation that the difference for the correct sentences across groups appeared to be somewhat more pronounced over the right hemisphere bears some interesting similarities to data observed in children during L1 acquisition. Using similar stimulus materials in seven-to-eight year-old children, we observed a positivity for syntactically incorrect sentences relative to correct sentences only over the right hemisphere (Friederici and Hahne, in press). This suggests that two subcomponents of the P600 may perhaps have to be differentiated by hemispheric differences. These two subeffects may bear some similarity to the difference between L1 and L2 acquisition. Further research will have to test these speculative assumptions.

Although there were also some descriptive differences between the correct sentences for earlier time windows (a more pronounced left anterior negativity around 200 ms and a somewhat less pronounced N400 component), these differences did not reach significance. Therefore we refrain from interpreting these. Future experiments with larger samples of bilingual participants will show whether these descriptive effects are of true significance.

Semantic violations in L2-learners elicited an amplitude modulation of the N400 component. The effect showed a right hemispheric distribution but was also significant for left posterior sites. The N400-effect did not differ statistically across groups, suggesting that semantic integration processes are very similar in L1 and L2 processing.

The centro-parietal N400-effect lasted about 400 ms longer in the L2 than in the L1 group. A longer extension of the N400 effect in bilingual readers was also reported by Kutas and Kluender (1991). The long extension of the N400 effect may indicate that

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Table 4. *Global analyses of ERP-effects (incorrect minus correct) for the three conditions across groups (L1 vs. L2)*

		semantic		syntactic			combined	
		400–700 ms	700–1100 ms	100–250 ms	500–1000 ms	700–1100 ms	100–250 ms	700–1100 ms
Source	*df*	*F*	*F*	*F*	*F*	*F*	*F*	*F*
Gr	1,26	< 1	6.92**	7.87***	1.91	4.24**	2.06	11.27***
Gr x He	1,26	2.27	6.74**	3.65*	4.66**	4.35**	6.43**	6.85**
Gr x Ap	1,26	< 1	1.74	6.86*	8.41***	8.11***	8.06***	3.94*
Gr x He x Ap	1,26	< 1	1.89	< 1	1.21	< 1	1.32	< 1

Gr = Group (L1 vs. L2); He = Hemisphere; Ap = Anterior–posterior dimension; *p < .10, ** p < .05, *** p < .01

Table 5. *Analyses of ERP-effects (incorrect minus correct) across groups (L1 vs. L2) for each region of interest for those comparisons in which condition interacted with hemisphere as well as with the anterior-posterior-dimension on a significance level of < .10 in the global analyses*

		syntactic			combined	
		100–250 ms	500–1000 ms	700–1100 ms	100–250 ms	700–1100 ms
Source	*df*	*F*	*F*	*F*	*F*	*F*
Gr						
left anterior	1,26	17.90***	< 1	< 1	14.96***	< 1
right anterior	1,26	7.65***	< 1	1.18	2.85*	5.29**
left posterior	1,26	2.36	4.74**	9.69***	< 1	10.14***
right posterior	1,26	< 1	7.69***	12.18***	2.21	21.12***

Gr = Group; *p < .10, ** p < .05, *** p < .01

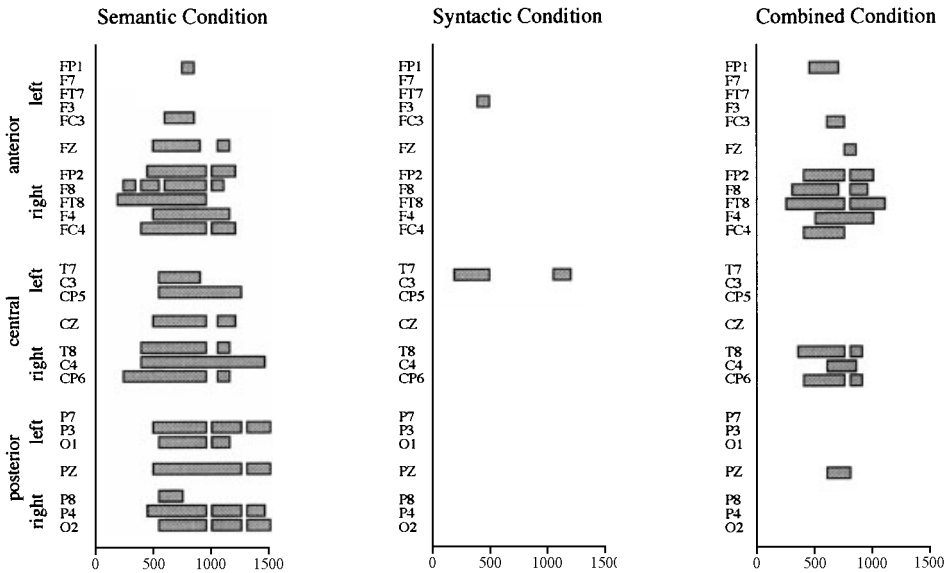


Figure 6. Results of the MANOVAs comparing each of the three incorrect conditions to the correct condition for each electrode, starting at the onset of the participle. Shaded bars indicate significant effects (p < .05). Effects are only marked whenever two or more successive 50 ms windows revealed a reliable effect.

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Table 6. *Global analyses of the correct condition across groups (L1 vs. L2)*

		correct			
		100–250 ms	400–700 ms	500–1000 ms	700–1100 ms
Source	*df*	*F*	*F*	*F*	*F*
Gr	1,26	< 1	< 1	4.70**	8.27***
Gr x He	1,26	3.47*	9.65***	7.93***	4.91**
Gr x Ap	1,26	< 1	< 1	< 1	1.09
Gr x He x Ap	1,26	< 1	< 1	< 1	< 1

Gr = Group (L1 vs. L2); He = Hemisphere; Ap = Anterior–posterior dimension; *p < .10, ** p < .05, *** p < .01

Table 7. *Analyses of the correct condition across groups (L1 vs. L2) for each hemisphere for those comparisons in which the interaction of condition and hemisphere reached a significance level of < .10 in the global analyses*

		correct			
		100–250 ms	400–700 ms	500–1000 ms	700–1100 ms
Source	*df*	*F*	*F*		*F*
Gr					
left	1,11	< 1	< 1	2.10	6.10**
right	1,11	< 1	1.98	6.27**	8.53***

Gr = Group; *p < .10, ** p < .05, *** p < .01

participants are engaged in trying to integrate the word into the prior context longer than native listeners. This might be a result of their uncertainty with respect to vocabulary knowledge and use. However, for the present data we cannot decide whether the extended difference between correct and incorrect sentences over parietal scalp sites is caused mainly by an N400 component for the semantic violations or by the large P600 for the correct sentences.

In addition, the semantic condition elicited a late right anterior-central negativity for incorrect sentences when compared to correct sentences. This effect was also observed in the combined condition and will be discussed below.

Syntactic violations did not elicit consistent and reliable ERP-modulation when compared to correct sentences. The small descriptive effects did not reach significance. By contrast, in native listeners we observed clear modulations in a biphasic early anterior negativity – P600 pattern.

The absence of the early anterior negativity effect taken to reflect first-pass parsing processes is not surprising, as these processes have been shown to be highly automatic in native listeners (Hahne and Friederici, 1999). This seems to suggest that the L2-learners' first-pass parsing processes have not reached the same status as they have for native listeners. The absence of the P600 modulation, moreover, indicates that the late processes also differ between L2- and L1-listeners. The absence of the P600-effect could be interpreted in two ways: it could either be due to the absence of late syntactic repair processes for the incorrect sentences or we could be faced with some kind of "floor-effect". As correct sentences elicited a particularly large positivity (which differed significantly from that shown by native listeners), the demands of syntactic integration in correct sentences perhaps induce a similar processing load as the repair-processes in syntactically incorrect sentences. As the behavioral data suggest that participants recognized the syntactic violations clearly above chance level, the amplitude of the positivity in the ERP (which was averaged only over correctly answered trials) may reflect violation-related processes rather than general processing demands of syntactic integration alone.

The ERP-results in the syntactic condition are partly compatible with earlier findings on the processing of phrase structure violations during reading (Weber-Fox and Neville, 1996) which observed an absence of a P600-effect in late L2-learners. In contrast to the biphasic early anterior negativity – P600 pattern observed in native listeners when listening to sentences containing a phrase structure violation (Friederici et al., 1993; Hahne and Friederici, 1999), a three-component pattern (N125, N300–500, P600) was reported when sentences containing a phrase structure violation were read (Neville et al., 1991). For late bilingual non-native readers, Weber-Fox and Neville (1996) found no modulations in the early left anterior negativity and the P600, but a significant negativity between 300–500 ms. As they do not provide a functional interpretation of the different components, it is not clear to what extent their data on reading is comparable to our data on listening.

The absence of a modulation of the early anterior negativity and of the P600 effect in our L2-group suggests that participants deviate from native listeners in the processing of syntactically incorrect sentences. This is also supported by their grammaticality judgment performance which was rather low in this condition. This result may be partially due to characteristics of their native language as preposi-

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tions do not exist in Japanese. Therefore, the expectancy for a noun after a preposition – which we assume to exist in native German listeners – might not occur in Japanese native listeners when learning German. We are currently exploring whether the observed results also hold for speakers of different native languages. First results seem to indicate that the ERP-pattern is quite similar for Russian and French native listeners: there was no modulation of the early anterior negativity and only a very small P600-effect.

It may be interesting to note that the absence of an early anterior negativity does not necessarily co-occur with an absence of a P600 effect. Studies with aphasic patients suffering from left anterior cortical lesions showed a P600 in the absence of an early anterior negativity effect when listening to sentences such as those used here (Friederici, Hahne and von Cramon, 1998; Friederici, von Cramon and Kotz, 1999). This demonstrates that the early syntactic component and the late syntactic component (P600) are functionally independent of each other (see also Hahne and Friederici, 1999).

Semantically and syntactically incorrect sentences differed significantly from correct sentences only at right anterior and right central electrode positions during the late time window (700–1100 ms) for the L2-group. This data pattern contrasts with that of native listeners, who demonstrated an early anterior negativity followed by a P600, though no N400, i.e. a pattern similar to sentences containing a syntactic violation only. The pattern for the L1-group suggests that once the parsing system identifies a word category error, lexical-semantic integration processes reflected by the N400 are blocked. Similar to native listeners, the L2 group did not display a centro-parietal N400-effect in the combined condition although they did show such an effect in the semantic condition, thus suggesting that the inappropriate preposition had been processed in some way, thereby influencing lexical-semantic integration processes.

Unlike native listeners, the L2 group showed a right anterior-central negativity for the semantic as well as for the combined violation condition. Whereas the combined condition differed significantly from the syntactic condition at these electrode sites, the combined condition did not differ significantly from the semantic condition at right anterior and central sites. As this effect was selectively observed only for those conditions which contained a semantic violation, it can be assumed that some type of semantic process is reflected in this ERP pattern. Since this effect was not observed in native listeners, these late processes performed in late L2-learners are functionally different from those performed by native listeners.[4]

Interestingly, a recent neuroimaging study also reported right frontal activity to be involved in the processing of semantic information in L2 in late bilinguals (Falk, Durwen, Müller, König, Müller and Heuser, 1999). Although our ERP data do not allow for a localization of the neural generators, the right anterior negativity in the present study together with the imaging data give rise to the following speculation about the nature and functional interpretation of the semantic process underlying these activations. Activation in the right frontal cortex was found to be associated with the processing of conceptual-semantic information during the processing of non-verbal meaningful material, e.g., visual scenes (Brewer, Zhao, Desmond, Glover and Gabrieli, 1998) and meaningful sounds (Opitz, Mecklinger, Friederici and von Cramon, 1999). Activation in the left frontal cortex was found to be associated with the processing of lexical-semantic information (Fiez, 1997; Gabrieli, Poldrack and Desmond, 1998). In a recent imaging study, differential activation patterns were observed for the same stimulus material (meaningful sounds) as a function of a verbal encoding task versus a non-verbal judgment task. The former task elicited activation in the left prefrontal cortex, the latter in the right prefrontal cortex (Opitz, Mecklinger, and Friederici, 2000). This suggests that the right prefrontal cortex supports the processing of conceptual-semantic information whereas the left prefrontal cortex subserves the processing of lexical-semantic information.[5] If the distributional pattern of the ERP negativity in the semantic and in the combined condition observed in the L2 group can be connected to the functional imaging data, the following hypothesis may be formulated. Late L2-

[4] The difference between correct and incorrect sentences, which we refer to as a right anterior central negative effect for semantically incorrect sentences, might rather be described as a larger positivity for correct sentences. Indeed, a comparison across groups indicates that the semantic violation condition is even more negative for the L1 than for the L2 group, whereas correct sentences elicited a significantly more positive waveform over the right hemisphere. The difference between correct sentences was interpreted as reflecting a greater difficulty in syntactic integration. However, the syntactic structure of the semantically incorrect sentences is identical to that of the correct sentences. This suggests that the difference between the correct and the semantic condition as well as the difference between the correct and the combined condition over right anterior-central electrode positions is more likely to be a reflection of additional processes based on semantic properties.

[5] Note that these results are in agreement with the theoretical distinction between conceptual-semantic and lexical-semantic aspects formulated in linguistics (Bierwisch and Schreuder, 1992).

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learners may, in their early learning stage, activate additional processes on the basis of conceptual processing. Lexical content may be identified independently of the lexical elements' morphological form (e.g. past participle form of a verb) and may activate the corresponding concept directly. Thus, in less proficient L2-users, semantic processes on a lexical level may be supplemented by semantic mapping processes between prior context and target element on a conceptual level. Further experiments using neuroimaging methods to investigate possible distributional differences in the hemodynamic response to semantic aspects of processing as a function of L2 efficiency are needed to show whether this hypothesis holds.

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