Brain Activity Associated with Syntactic Incongruencies in Words and Pseudo-Words

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Abstract

Event-related brain potentials (ERPs) were recorded while normal German subjects read either simple declarative sentences made up from real German words, or sentences that contained German pseudo-words instead of nouns and verbs. The verb (pseudo-verb) of the sentences disagreed in number with the subject noun (pseudo-noun) in 50% of the sentences. The subjects had the task either to read the sentences for an interspersed memory test (memory condition, pseudo-word sentences only) or to make a syntactic judgment after each real-word/pseudo-word sentence.

While in the real-word condition a late and widespread positivity resembling the previously described syntactic positive shift was found for the disagreeing verbs, a negativity with an onset latency of about 300 msec was seen for the disagreeing pseudo-verbs. In the pseudo-word conditions no positivity followed the initial negativity. This dissociation of negative and positive waves occurring in response to morphosyntactic mismatches by the pseudo/real-word manipulation suggests that the positive shift is a concomitant of a recomputation routine initiated to account for the number incongruency. This routine is based upon the semantics of the sentence and therefore is not observed in the pseudo-word conditions. The earlier negativity, on the other hand, appears to be a more direct index of morphosyntactic incongruency.

INTRODUCTION

One of the key issues in psycholinguistics is the organization of the language-processing system: one group of researchers advocating a modular architecture with separate and separable processing modules for the analysis of, e.g., semantic, syntactic, and pragmatic aspects of an utterance with an integration of the information only at a late stage (Fodor, 1983; Forster, 1979; Bock & Kroch, 1989; Frazier, 1987) is opposed by scientists who envision a connectionist language-processing network with continuous integration of information from all sources (Ades & Steedman, 1982; Elman, 1990; MacWhinney, Bates, & Kliegl, 1984; McClelland, St. John, & Taraban, 1989). So far, both groups of researchers have presented evidence in favor of their theory but the debate has not been settled.

This state of affairs provided the impetus for a vigorous search for alternative measures of sentence processing, especially in the field of event-related brain potentials (ERPs). ERPs have been shown to be useful indicators of language processes over the last few years. A wealth of data has accumulated concerning the relationship of a monophasic negativity peaking about 400 msec after the presentation of a word (the N400) to various language-related parameters (for reviews see Kutas & Van Petten, 1988; Fischler, 1990; Halgren, 1990; Osterhout & Holcomb, 1992). The N400 amplitude has usually been found to be smaller for words that had been contextually or semantically primed (e.g., Bentin, McCarthy, & Wood, 1985; Münte, Klunker, & Heinze, 1989), words that were repeated (Besson, Kutas, & Van Petten, 1992; Rugg & Doyle, 1994), words that occur with a higher frequency in normal language (Rugg & Doyle, 1994), and words that were presented in a context consistent with an episodic memory trace (Fischler et al., 1984).

Besides investigations into the ERP effects of lexical, sentential, and semantic factors, there have been a number of attempts to characterize the ERP correlates of syntactic processing with the long-range goal to be able to test theories of human parsing (e.g., Kutas & Kluender, 1994, Osterhout & Holcomb, 1995; Neville et al., 1991; Rösler et al., 1993). In some of the studies, local morphosyntactical incongruencies (number or case disagreements) have been presented within or at the end of
followed by a broad positivity that extended well into for the morphosyntactical incongruencies, which was followed by a broad positivity that extended well into the presentation of the next word (Kutas & Hillyard, 1983; Coulson, King, & Kutas, 1995, Münte & Heinze, 1994, Friederici et al., 1993). In a study by Münte and Heinze (1994), morphosyntactic (case disagreement) errors were contrasted with semantic and orthographic errors with a story-reading experiment. In this experiment, a frontally distributed negativity in the 250-500 msec range was seen for the morphosyntactic errors, while a centrally distributed negativity was seen for the semantic errors. On the other hand, a positivity with similar characteristics was found in the later time windows for both conditions. A tentative interpretation would be that the initial negativity occurs directly in response to the morphosyntactical mismatch while the later positivity is the concomitant of a more general recomputation process.

However, in a number of studies, only the broad positivity was found in response to the syntactic incongruencies (Hagoort et al., 1993; Osterhout & Holcomb, 1992). Hagoort et al. (1993) interpreted this positivity as being specific for syntactic incongruencies, coining the term "syntactic positive shift." The general scalp distribution and the occurrence of this positivity suggest a relationship to the later positivity (syntactic positive shift) occurring in a wide range of experimental contexts and has been thought to reflect a context-updating routine (Fabiani et al., 1988). A recent study by Coulson et al. (1995) addressed the relationship of the syntactic positive shift and the late positive component by manipulating (a) the morphosyntactic congruency (pronoun case and verb number) of words and (b) the probability of morphosyntactic errors in a sentence-reading task. As probability and morphosyntactic incongruency showed strong interaction effects on the positivity, Coulson et al. (1995) concluded that the syntactic positive shift belongs to the P300 family of components.

In the present study we were concerned with the respective functional correlates of the earlier negativity and the late positivity (syntactic positive shift) occurring in response to morphosyntactic incongruencies. Specifically, we sought to substantiate our hypothesis that the late positive component is a correlate of recomputational processes necessary when one encounters an incongruency within a sentence, while the earlier negativity represents a more specific measure of syntactic congruency. The present investigation tries to address this question by using sentences made up from pseudo-words and manipulating the morphosyntactical congruity of the sentence constituents, i.e., the pseudo-noun (subject) and the pseudo-verb. The study exploited the fact that morphosyntactical features in the German language are in many cases unambiguous, and only such unambiguous pseudo-words were used. The sentences used had the same stereotyped structure in that they contained five words (denominator - noun/subject - verb - denominator - noun/object) and were presented visually on a monitor. The (pseudo)noun/subject and the (pseudo)/verb either matched or mismatched as far as the number was concerned (for details, see Methods). The following sentences represent examples of the four different sentence types for the pseudo-word experiment:

(1) Der Kruke plötz den Schрук
    A flurk nerches the minch
Singular - match

(2) * Das Kleckn frunen den Wech
    A mizzel quanch the phurr
Singular - mismatch

(3) Viele Wenken donzen den Tend
    Many flizzies brin the chink
Plural - match

(4) * Manche Verzinker trögelt den Blotz
    Some globbies biggles the vlinch
Plural - mismatch

Thus, a setting was created in which the ERP correlates of syntactic processing, in particular simple number matching, could be studied in absence of meaning. The sentences made up from pseudo-words were presented in two conditions: In Experiment 1 (memory condition) the task of the subject was to read the sentences, and to indicate for test sentences presented after sets of five sentences whether or not these constituted an identical repetition of one of the previously seen sentences. In Experiment 2 (judgment condition) the same sentences were presented with the task to indicate after each sentence whether this was syntactically possible or not. For the purpose of comparison, sentences made up from real words were presented as well (Experiment 2 only):

(5) Der Junge schlägt den Hund
    The kid beats the dog
Singular - match

(6) * Der Mann trinken das Bier
    The man drink the beer
Singular - mismatch

(7) Viele Passagiere zahlen die Fahrkarten
    Many passengers pay the tickets
Plural - match

(8) * Manche Lehrer bestraft die Schüler
    Some teachers punishes the students
Plural - mismatch

Should we find the earlier negativity to the number mismatches in the pseudo-word conditions, this would argue strongly in favor of the view that it is a specific indicator of morphosyntactic incongruency. Moreover, on the basis of the hypothesis that the late positivity might reflect an unspecific recomputation necessary on encountering an error of any kind during sentence processing, it was predicted that in the pseudo-word cond-

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tion no such effect should occur since no meaningful representation could be extracted from these sentences.

RESULTS

Experiment 1

Memory Performance

The memory performance in the foil task was better than 86% for all subjects.

ERPs

The grand-average ERPs for the entire sentences are given in Figure 1. For each of the stimuli a negative-going initial deflection (peak latency approximately 70 msec) is followed by a positivity with a peak latency of 200 msec relative to word onset. It is apparent that no differences are visible for the parts of the waveforms preceding the (pseudo)verbs. The (pseudo)verbs that did not match the preceding noun for number were associated with a more negative-going waveform starting with an onset latency of about 280 msec relative to the onset of the verb and extending to 600 msec (Fz) to more than 800 msec (Pz).

The waveforms to the (pseudo)verbs are depicted in Figure 2. Clearly, the widespread distribution of the additional negativity for the number disagreements is seen. It appears that the effect is slightly more prominent over the left hemisphere than the right. Furthermore, for the lateral sites, a frontocentral maximum is observed with no effect at the lateral parietal sites.

The statistical results are summarized in Table 1. Since no main and interaction effects regarding topography factors were revealed these results were omitted.

Experiment 2

Grammaticality Judgments

Grammaticality judgments were virtually perfect in the RW condition (99.6%). For the PW condition, the data for the grammaticality judgments revealed that the subjects were able to distinguish agrammatical from grammatical pseudo-sentences (96.2%).

Figure 1. Grand average (n = 12) ERPs over the entire sentence from the pseudo-word experiment with memory instructions. The vertical line marks onset of the pseudo-verb. The preceding words (denominator pseudo-noun/subject) occur at -1600 and -800 msec, the two words following the verb at 800 and 1600 msec. The pseudo-verbs mismatching the subject as far as number is concerned are characterized by more negative waveform starting at 280 msec after onset and extending up to approximately 800 msec. The waveforms are aligned for a 100-msec baseline preceding the onset of the verb.
Figure 2. ERPs to the pseudo-verb in the experiment with memory instructions. The distribution of the number-incongruency effect can be appreciated, being widespread and having a slightly higher amplitude over the left hemisphere.

ERPs

The grand-average ERPs for the entire sentences are depicted in Figure 3 for the pseudo-words. Again, no appreciable difference between correct and incorrect sentences is present for the word prior to the verb. The pseudo-verbs having the wrong number are characterized by a more negative waveform beginning at about 280 msec and extending to about 500 msec. This effect is seen only for the central and parietal leads.

The corresponding waveforms of the real-word sentences are shown in Figure 4. While no difference is seen for the first two words of the sentence, the verb is followed by a long-lasting positive shift beginning at approximately 400 msec after onset of the verb and extending well into the ERP to the next word. This positivity had a centroparietal maximum.

Statistical Results

The statistical results for the congruity factor of the three conditions (pseudo-word/memory, pseudo-word/judgment, real-word/judgment) are given in Table 1. Since no main or interaction effects were revealed regarding the topography factors (electrode/sagittal, hemisphere), these are omitted from the table. The additional negativity to the number errors in the pseudo-word conditions is reflected in main effects of congruity extending from time windows 300-500 msec to 500-700 msec in the memory condition and 300-500 msec in the judgment condition. The greater positivity found in the real-word/judgment condition was corroborated by main effects of congruity in the later time windows (500-700 msec to 700-900 msec).

Since the two judgment conditions were run in the same subjects, an ANOVA with sentence type (real-word vs. pseudo-word) was conducted for Experiment 2 with selected results given in Table 2. Congruity x Sentence Type interactions were revealed for the later time windows, reflecting the strikingly different effects in the real-word and pseudo-word conditions.

Comparison of the Experiments

The grand-average ERPs to the verbs of the three conditions are depicted in Figure 5 for the three midline
Figure 3. ERPs over the entire sentence from the pseudo-word experiment with judgment instructions. The vertical line marks the onset of the pseudo-verb. The preceding words (denominator, pseudo-noun/subject) occur at -1600 and -800 msec, the two words following the verb at 800 and 1600 msec. As in the experiment with memory instructions, mismatching pseudo-verbs are characterized by a more negative waveform beginning at approximately 180 msec. This effect is not as prolonged as in the experiment with memory instructions (see also Fig. 5).

Table 1. Main Effects of Congruity in the Three Conditions

<table>
<thead>
<tr>
<th>Time Window (msec)</th>
<th>Memory Pseudo-Words</th>
<th>Judgment Pseudo-Words</th>
<th>Judgment Real-Words</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F(1, 11)</td>
<td>p-level</td>
<td>F(1, 11)</td>
</tr>
<tr>
<td>100-300</td>
<td>1.82</td>
<td>0.04</td>
<td>0.42</td>
</tr>
<tr>
<td>300-500</td>
<td>10.71</td>
<td>0.005</td>
<td>5.47</td>
</tr>
<tr>
<td>500-700</td>
<td>5.31</td>
<td>0.05</td>
<td>3.74</td>
</tr>
<tr>
<td>700-900</td>
<td>0.73</td>
<td>n.s.</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Table 2. Comparison of Real-Words and Pseudo-Words (Judgment Condition)

<table>
<thead>
<tr>
<th>Time Window (msec)</th>
<th>Congruity</th>
<th>Sentence Type</th>
<th>Congruity × Sentence Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F(1, 11)</td>
<td>p-level</td>
<td>F(1, 11)</td>
</tr>
<tr>
<td>100-300</td>
<td>0.52</td>
<td>n.s.</td>
<td>1.32</td>
</tr>
<tr>
<td>300-500</td>
<td>1.94</td>
<td>n.s.</td>
<td>3.89</td>
</tr>
<tr>
<td>500-700</td>
<td>12.53</td>
<td>0.005</td>
<td>1.67</td>
</tr>
<tr>
<td>700-900</td>
<td>41.31</td>
<td>0.001</td>
<td>5.91</td>
</tr>
</tbody>
</table>
Figure 4. ERPs over the entire sentence from the real-word experiment with judgment instructions. The vertical line marks the onset of the verb. The preceding words (denominator, noun/subject) occur at -1600 and -800 msec, the two words following the verb at 800 and 1600 msec. The mismatching verb gives rise to a long-lasting positivity beginning at about 400 msec and extending into the waveform of the following word. For this effect a parietal maximum is apparent.

electrodes, showing that for the two pseudo-word conditions an additional negativity was elicited by the number errors, while for the real-word/judgment task only an additional positivity was found.

For the purpose of comparison, data from a related experiment (Miunte & Heinze, 1994) are also depicted. These are waveforms to nouns that either had the correct case or not. The task of the subjects was to read a story for comprehension. Under these circumstances, a negativity followed by a positivity was revealed for the case mismatches.

Sentence Terminal Words

In the present experiment, the waveforms to the sentence terminal words are of additional interest. It has been shown in several instances (e.g., Hagoort et al., 1993; Garnsey, Tanenhaus, & Chapman, 1989) that syntactic errors within a sentence can lead to an altered waveform for the sentence terminal word taking the form of an N400 component. This is thought to be due to difficulties in the semantic processing of the sentence containing the syntactic error. For the present experiment it was proposed that only in the real-word condition such difficulties should arise, and therefore only in this condition was an N400 component expected. The grand-average ERPs to the terminal words are depicted in Figure 6, showing an additional negativity for the real-word condition beginning at about 250 msec and having a centro-parietal maximum, while the two pseudo-word conditions did not show an effect. This was corroborated by statistical analyses that did not show a main effect of congruity in the two pseudo-word conditions, while for the real-word condition main effects of congruity were revealed for time windows 300-500 to 500-700 msec (all F(1, 11) > 7.2, all p < 0.025).

DISCUSSION

The aim of the present study was to delineate the electrophysiological effects of morphosyntactic incongruences and, more specifically, to dissociate the previously described late positivity (syntactic positive shift, SPS, e.g., Hagoort et al., 1993; Osterhout & Holcomb, 1992) from an earlier negativity that has variously been found in response to morphosyntactic mismatches (e.g., Kutas &
Hillyard, 1983; Münte & Heinze, 1994; Coulson et al., 1995). In fact, the two electrophysiological effects have been found to be affected differently by the experimental manipulations. Therefore we will discuss the two effects separately.

**Negativity**

In response to the morphosyntactic mismatch, a negativity was seen in both experiments using German pseudo-words. Thus, it appears that brain potentials reflect morphosyntactic errors in absence of any semantic content. Moreover, its presence in the memory condition that did not require evaluation of the syntactic relationship of the pseudo-words for the execution of the task, suggests that the negativity occurs in an obligatory fashion whenever an error is encountered. We will elaborate on this important point in a subsequent portion of this discussion.

In contrast, no negative effect was discernible in the real-word judgment condition. In a related experiment (Münte & Heinze, 1994), we had presented case-agreement errors in nouns within stories and showed both a negativity and a positivity in response to the errors. In the latter study, the subjects had the task simply, to read stories for comprehension, and the errors occurred only very infrequently.

In a recent study by Coulson et al. (1995), number errors and pronoun case errors (e.g., “Charles doesn’t like to shave because him tends to cut . . .”) were presented within sentences with the subjects reading for comprehension. Under these conditions the negativity was much more pronounced for the pronouns, presumably because pronoun errors disrupted sentence processing more profoundly.

Thus, it appears that two factors might influence the presence and amplitude of the negativity: from the Coulson et al. (1995) study it appears that saliency of the error is an important factor. The comparison of the real-word judgment condition with the data from our story-
reading experiment suggests that overlap with the late positive shift under some experimental conditions might mask the negative component occurring in response to morphosyntactic errors. The fact that a judgment was required in the present study could be responsible for a slightly earlier positivity, thus masking the negative component.

Since no positivity was present in the pseudo-word conditions, the view is supported that the positivity described as the syntactic positive shift does occur only when a reprocessing of a sentence is required. This is corroborated by a series of studies in which we have presented word-pairs that either formed a syntactically permissible mini-phrase (e.g., my - laughter) or not (e.g., you - laughter). These studies were performed in English (Münte, Heinze, & Mangun, 1993; Adamson, Münte, & Mangun, in press), German (Münte & Heinze, 1994; Rohs & Münte, 1995), and Finnish (Münte & Heinze, 1994) and revealed a monophasic negativity to the incongruent second words of a pair with an onset at about 300 msec and a peak latency at about 500 msec. This negativity was largest when the subjects attended to the morphosyntactical relation between the stimuli (syntactic judgment task), but was also present in tasks that did not require the subjects' processing of the syntactical relation of the two words (letter monitoring, lexical decision). No late positivity (or syntactic positive shift) was found in these studies. It seems safe to conclude that for these word-pairs no (or only minimal) reprocessing was necessary when a mismatching word was encountered, since no sentence structure was present.

The question arises as to how the negativity observed in the present experiment is related to other negativities commonly seen in language experiments, notably the N400 and the LAN (left anterior negativity; King & Kutas, 1995). While the N400 has been tightly linked to semantic processing, and has been normally found to display a centroparietal distribution with a slight right preponderance, the LAN has been found in structurally similar sentences that differed in their working memory load and was maximal over left anterior scalp sites.

In some of the word-pair experiments (Münte et al., 1993; Adamson et al., in press) we have contrasted semantic and syntactic mismatches using the same material and employing 32- and 64-channel recording devices. The negativities to the syntactic mismatches showed a more anterior distribution compared with the semantic condition, and we therefore concluded that at least partially different neuronal populations are active in the two tasks. Similar distributions for the negativity were seen in some sentence-reading tasks (Kutas & Hillyard, 1983; Münte & Heinze, 1994).

The current experiments, while employing only 13 scalp electrodes, showed a different distribution of the negativities to morphosyntactic incongruencies in that a more central maximum was obtained. Also, in an earlier study presenting syntactically incongruent words in sentence terminal positions in German (Münte et al., 1990), we had observed a more central maximum.

The factors that govern the differential distribution of the negativities in response to morphosyntactic mismatches are not clear and require further systematic...
experimentation using multichannel arrays. Therefore an in-depth discussion of the relationship of the current negativities to the N400 and LAN seems premature at present.

**Positivity**

A positivity resembling the syntactic positive shift (P600) was found only in the real-word condition, in which it had an onset latency of roughly 400 msec extending well into the ERP to the next word. This positivity resembles those described by Hagoort et al. (1993), Osterhout and Holcomb (1992), Coulson et al. (1995), and Münte and Heinze (1994). Its distribution was widespread with a centro-parietal maximum suggesting its relationship to the late positive component (P300) found in a multitude of experimental conditions. This relationship has been addressed in recent investigations (Coulson et al., 1995).

While the question of the syntactic positive shift being a domain-specific or domain-general electrophysiological phenomenon is not aimed at by the present investigation, the absence of the positivity in the two pseudo-word conditions argues against the notion that the positivity reflects a process involved in the detection of a morphosyntactic mismatch per se. In conjunction with our finding that under conditions of very infrequent syntactic, semantic, and orthographic errors a positivity can be seen for all three error classes, the present findings suggest that (1) the processing routine underlying the late positivity is called upon whenever a reprocessing of a sentence is necessary, and (2) that it is not a necessary concomitant of a morphosyntactic mismatch.

An alternative hypothesis is that the positivity defined as the difference between the correct and the incorrect version of a sentence represents a disruption of a very slow ramp-shaped CNV-like activity building up over the course of sentence. Kutas and Van Petten (1991) have contrasted sentence-based averages to sentences conveying an intelligible message with “syntactic prose” sentences (e.g., “Yellow fathers smoked the kitchen without a car.”) and found that only in the former condition was a ramp-shaped negativity present. Visual inspection of the sentence-based averages of the present experiments likewise reveals that only in the real-word condition a negative shift occurred, which is present even prior to the critical word.

Both interpretations of the positivity (correlate of reprocessing, disruption of ramp-shaped negativity) are not distinguishable in light of the present data. However, the important point here is the dissociation of negative and positive components. Figure 6 illustrates this dissociation in a summarizing fashion. Figure 6A shows the difference waves obtained by subtracting the ERPs to the correct critical words from those to the incorrect critical words in a point-by-point fashion. The negativity is seen most clearly for the memory condition of the present study and is less pronounced for the pseudo-word judgment condition, having an onset latency of about 250 msec. In these conditions, requiring no recomputation of the sentence, no positivity is seen. By contrast, the difference waves from the story-reading task (Münte & Heinze, 1994) displayed both a negativity and a positivity, while the current real-word judgment condition only showed a positivity with a slightly earlier onset. It is conceivable that the earlier onset of the positivity in the real-word judgment condition led to the cancellation of the negativity. Figure 6B shows the hypothetical time course of the two ERP effects that appear to be evoked independently from each other.

**Consequences for Models of Language Processing**

On a more general level, it has to be asked how the present data bear on current discussions of models of language processing. A major front line runs between those who conceptualize a modularized processing system (Bock & Kroch, 1989; Forster, 1979; Fodor, 1983) and those who envision an interactive network-like architecture for the language-processing system (Ades & Steedman, 1982; Elman, 1990; MacWhinney et al., 1984). The latter theorists do not believe that a separate processing module dedicated to the analysis of morphosyntactic features exists that operates without the knowledge of other information (semantic, pragmatic). Consequently, an ERP effect sensitive to purely morphosyntactic features/incongruencies would not be predicted by purely interactive models. Models have appeared, however, that implement a network approach for a given module. For example, Sokolik and Smith (1992) have presented a computer simulation of gender-assignment in French nouns that could successfully assign the gender to up to 79% of untrained nouns. If one envisions a circumscribed cortical area dedicated to the processing of morphosyntactic features but operating in a network-like fashion, an ERP effect to morphosyntactic feature extraction is conceivable.

From the present data it appears that the negativity seen in both pseudo-word conditions might represent such a component. Its occurrence in the absence of other types of language information suggests that it is sensitive to morphosyntactic features and that such features are extracted automatically even if the task (e.g., memory condition of the present study) does not require such an analysis. This observation attests to the notion that ERPs are capable to decide between different kinds of language models, and in this specific case they weigh heavily against purely interactive models. Clearly, further studies have to address the relationship of the negativity seen here with other negativities (N400, LAN) observed in language tasks, in particular if they share common neural generators. However, this does not impair the use of the negativity for the investigation of morphosyntactic processing.
METHODS

Subjects

Two different groups (each n = 12) of native speakers of German (13 women, age range 20-32, all right-handed) participated in the two experiments. The data of seven additional subjects (Ss) had to be discarded because of excessive artifacts (criterion: more than 35% of the trials rejected). All Ss were healthy and had normal or corrected-to-normal vision.

Experiment 1 (Memory Condition)

For the first study, 240 “sentences” were constructed with German pseudo-words serving as noun/subject, verb and noun/object. All the sentences had the same stereotyped structure in that they contained five words (denominator - noun/subject - verb - denominator - noun/object). Care was taken that the pseudo-words did not contain letter combinations uncommon in German, such that these words sounded word-like. The (pseudo)noun/subject and the (pseudo)verb either matched (50%) or mismatched (50%) as far as the number was concerned. This is possible in German, as the default ending of a singular regular verb is -t (present tense) and the default plural ending is -en. For the (pseudo)noun/subject words the number was determined jointly by the preceding word (e.g., Das = The/neutral gender/singular, Der = The/masculine gender/singular, Viele = Many, Manche = Some, etc.) and the ending of the (pseudo)noun. The endings of the (pseudo)nouns were chosen based upon the experimenter’s intuition and agreed upon by several members of the lab. Examples of the sentences have been given in the Introduction.

The sentences were presented word by word on a video monitor with word durations of 200 msec and word onset asynchronies of 800 msec. The stimuli appeared in green capital letters in the middle of the video screen within a dot matrix subtending 5.7° of visual angle in width and 1.2° of visual angle in height at the chosen viewing distance of 90 cm. The dot matrix appeared 400 msec before the first stimulus of a sentence and was present until 1500 msec after the last word. The interval between sentences varied randomly between 2000 and 5000 msec. Every five sentences a “test sentence” appeared on the screen for a duration of 3000 msec that was an exact or slightly altered repetition of one of the preceding five sentences. The alteration consisted of the exchange of one pseudo-word (excepting the critical words). Thus, the syntactic structure was never changed between the original occurrence of a sentence and the test sentence. The Ss were asked to press one of two buttons according to whether or not the test sentence was an exact repetition. They were unaware of the fact that the experiment addressed syntactic processing; rather, they were told that the study tested their immediate memory for nonsense sentences.

The 240 sentences were presented in random order regarding their type in 12 blocks of 20.

Experiment 2 (Judgment Condition)

The stimuli of the first experiment were used. In addition, 240 sentences containing real-words at all positions and having the same stereotyped structure as the pseudo-word sentences were constructed. Only present-tense sentences were included (see Introduction). The timing and mode of presentation of the sentences was identical to Experiment 1 with the exception that 1500 msec after the last word the question “grammatical? - ungrammatical?” was flashed on the screen, requiring the subject to indicate, by pressing one of two buttons, whether the preceding sentence would be regarded grammatically well-formed or not. Again, sentences were presented in blocks of 20. A block contained either pseudo-word (PW) sentences or real-word (RW) sentences. Six RW blocks and six PW blocks were presented during each of two sessions. The order of the conditions was randomized between the subjects.

EEG Recording and Waveform Quantification

The EEG was recorded from 11 scalp sites—F3/F4, C3/C4, P3/P4, Fz, Cz, Pz, and T3/T4 (Experiment 1 only) or Fp1/Fp2 (Experiment 2 only) according to the international 10/20 system—against a reference electrode placed on the left mastoid process using tin electrodes mounted in a special cap (Electro-Cap). A bipolar derivation was used to record eye blinks for artifact rejection purposes. The biosignals were amplified with a Van Gogh polygraph with time constants set to 10 sec and low-pass filter settings of 35 Hz. The AD conversion was done with 9 msec resolution. After artifact rejection and filtering using a special purpose program (Scholz et al., 1989), averages were computed according to the different stimulus classes and conditions. The Scholz et al. (1989) program is based on rejection of contaminated EEG segments on the basis of voltage criteria for the eye channels and detection of amplifier blocking for all channels. This is followed by bridging the rejected portions by cubic functions and application of a digital filter. In order to lose only a low number of trials for the analysis on the critical words, different types of averages were computed: (a) averages with a 1200-msec epoch length beginning 200 msec prior to the presentation of the verb, and (b) averages with an epoch comprising the duration of the whole sentence. The latter were baselined relative to the 100 msec preceding the verb-stimulus.

The brain responses to the verbs were of primary interest here. Thus, only the ERPs to the third word of a sentence were quantified for later statistical evaluation.
Area measures were employed exclusively because they are known to be less sensitive to noise. The measurements were made relative to a 100-msec prestimulus baseline (onset of the verb) in successive time windows of 200-msec duration (100–300 msec, 300–500 msec, etc.). The statistical evaluation was accomplished using repeated measures analyses of variance (ANOVA). For Experiment 1, the following factors applied: congruity (levels: correct vs. incorrect), electrodes/sagittal (levels: frontal, central, parietal), hemisphere (levels: left, right). For Experiment 2, different sets of analysis were carried out: an overall ANOVA included a Sentence Type (levels: real vs. pseudo-sentence) factor in addition to the above-mentioned factors. Furthermore, separate sets of ANOVAs were carried out for the real-word sentences and the pseudo-word sentences. The Greenhouse-Geisser epsilon correction was used and reported p-values are corrected.

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Note

1. An additional set of analyses was carried out for the midline electrodes with Fz, Cz, and Pz as levels of a site factor. As these revealed similar results they will not be considered here.

REFERENCES


