

# Setting the Stage for Automatic Syntax Processing: The Mismatch Negativity as an Indicator of Syntactic Priming

Anna S. Hasting, Sonja A. Kotz, and Angela D. Friederici

## Abstract

■ The present study investigated the automaticity of morphosyntactic processes and processes of syntactic structure building using event-related brain potentials. Two experiments were conducted, which contrasted the impact of local subject–verb agreement violations (Experiment 1) and word category violations (Experiment 2) on the mismatch negativity, an early event-related brain potential component reflecting automatic auditory change detection. The two violation types were realized in two-word utterances comparable with regard to acoustic parameters and structural complexity. The grammaticality of the utterances modulated the mismatch

negativity response in both experiments, suggesting that both types of syntactic violations were detected automatically within 200 msec after the violation point. However, the topographical distribution of the grammaticality effect varied as a function of violation type, which indicates that the brain mechanisms underlying the processing of subject–verb agreement and word category information may be functionally distinct even at this earliest stage of syntactic analysis. The findings are discussed against the background of studies investigating syntax processing beyond the level of two-word utterances. ■

## INTRODUCTION

A fair amount of brain processes escapes our conscious awareness. Sensory inputs are constantly monitored and evaluated. We can accomplish rather complex tasks like staying balanced on a bicycle without any apparent effort. Processes like these, which are very fast, occur involuntarily and do not produce interference with other ongoing mental activity, are defined as automatic (Schneider, Dumais, & Shiffrin, 1984; Posner & Snyder, 1975). They allow us to perform the most complex forms of behavior in a habitual manner. The current article concerns their relevance for one of the most elaborate human skills: The ability to analyze and understand the complex syntactic structure of language.

At first glance, syntactic analysis appears to fulfill most of the conditions for being classified as automatic. To measure up to the enormous speed at which we are confronted with language, it needs to be very fast. Furthermore, analyzing syntax does not seem to require much of our conscious control or attentional resources. However, evidence from empirical studies using event-related brain potentials (ERPs) suggests that not all steps in syntactic analysis are performed automatically.

The ERP method provides a real-time correlate of the electrical brain activity elicited by a given stimulus. Because of its high temporal resolution, it is particularly suitable for the investigation of language processing as it unfolds in time. To date, three functionally distinct ERP components related to syntactic processing have been identified. In response to violations of word category, which disrupt local syntactic structure building processes, a very early left anterior negativity (ELAN) occurs at around 150 msec after the onset of the critical morpheme (Friederici, Hahne, & Mecklinger, 1996; Neville, Nicol, Barss, Forster, & Garrett, 1991). In contrast, morphosyntactic violations that leave the syntactic structure intact but affect tense, number, or gender agreement elicit a slightly later left anterior negativity (LAN) between 300 and 500 msec post word onset (Coulson, King, & Kutas, 1998; Osterhout & Mobley, 1995; Friederici, Pfeifer, & Hahne, 1993; Kutas & Hillyard, 1983). Finally, both types of syntactic violations result in a late centro-parietal positivity termed P600 or “syntactic positive shift” (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992), which has also been observed in response to syntactic complexity (Kaan, Harris, Gibson, & Holcomb, 2000) and ambiguity (Frisch, Schlesewsky, Saddy, & Alpermann, 2002). A recent neurocognitive model of auditory sentence comprehension suggests that the three syntactic ERP components reflect three consecutive phases of syntactic

---

Max Planck Institute for Human Cognitive and Brain Sciences,  
Leipzig, Germany

processing. In a first step, information about a word's category is extracted, and an initial syntactic structure is built based on this information. Second, morphosyntactic information is retrieved and integrated with the structural information. In the third phase, processes of reanalysis and repair occur if the initially assigned structure needs to be revised (Friederici & Kotz, 2003; Friederici, 2002).

Importantly, ELAN, LAN, and P600 have been shown to differ not only in timing and topography, but also in their respective automaticity. The ELAN was shown to be unaffected by variations of violation probability (Hahne & Friederici, 1999) or task demands (Hahne & Friederici, 2002) and is therefore assumed to be reflecting an automatic process. In the case of the LAN, the evidence is less clear: Although similarly unaffected by violation probability (Gunter, Stowe, & Mulder, 1997), it seems to be modulated by working memory load (Vos, Gunter, Kolk, & Mulder, 2001), which speaks against a truly automatic process. In contrast, the P600 was found to be reduced in conditions where the violation probability is high (Hahne & Friederici, 1999; Gunter et al., 1997) and under shallow processing demands (Gunter & Friederici, 1999) and is thus considered to be reflecting a controlled process. This pattern of results strongly suggests that merely the earliest stage in syntactic analysis (i.e., syntactic structure building based on word category information) is fully automatic, whereas later stages are, at least to some degree, subject to attentive processing.

However, recent evidence from research utilizing the mismatch negativity (MMN) to study automatic syntax processing challenges the view that processes of syntactic structure building and morphosyntactic processes are distinguishable based on their respective temporal and attentional characteristics. The MMN is a well-studied auditory ERP component that reflects the detection of deviations in strings of standard stimuli, typically peaks between 100 and 200 msec after auditory change onset and is usually maximal at fronto-central recording sites (Näätänen, Gaillard, & Mäntysalo, 1978; for a recent review, see the work of Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001). Originally reported in response to changes in 1-D auditory features such as frequency, duration, or intensity, the MMN has recently been extended to the study of more complex representations such as abstract rules (e.g., Paavilainen, Simola, Jaramillo, Näätänen, & Winkler, 2001; Tervaniemi, Maury, & Näätänen, 1994) and elements of speech (e.g., Näätänen, 2001). Importantly, the MMN has been shown to be independent of attentional resources (Näätänen, 1992), which makes it a particularly suitable tool for the investigation of automatic processes. Making use of this advantage, Pulvermüller and colleagues developed a paradigm that tests the impact of syntax processing on the MMN. In one of their studies, utterances of minimal English sentences (subject NP plus verb), which were syntactically congruent or violated

subject-verb agreement, were contrasted as standard and deviant stimuli in an MMN protocol (Pulvermüller & Shtyrov, 2003). The utterances differed only in their final phoneme, which also determined their grammaticality (e.g., *we come* vs. *\*we comes*). To control for the effect of the auditory difference between the utterances, the critical words *come* and *comes* were additionally contrasted in the absence of any linguistic context. Compared with this baseline condition, the amplitude of the MMN was significantly reduced if the deviant phrase was grammatically correct. The effect occurred around 150 msec as measured from the diverging final phoneme of the utterances. A similar study that investigated subject-verb agreement violations in short Finnish utterances produced comparable results (Shtyrov, Pulvermüller, Näätänen, & Ilmoniemi, 2003). These findings indicate that the MMN is sensitive to morphosyntactic processing. The authors attribute the observed amplitude modulation of the MMN to syntactic priming, a phenomenon that was first reported in behavioral studies showing that syntactic context facilitates word recognition (e.g., Schriefers, Friederici, & Rose, 1998; Deutsch & Bentin, 1994; Wright & Garrett, 1984; Goodman, McClelland, & Gibbs, 1981). Pulvermüller (2002) suggests that at the neuronal level, syntactic priming is mediated by so-called sequence detectors linking the lexical representations of morphemes that are likely to occur in succession. According to this theory, a sequence detector automatically preactivates, or primes, syntactically valid morphemes and thereby facilitates their processing. In light of this interpretation, the grammaticality effect on the MMN is regarded as an "error signal," which occurs if an unexpected and, therefore, unprimed morpheme is encountered (see Shtyrov et al., 2003).

The finding that the brain's automatic mismatch detection response is modulated by morphosyntactic violations as early as 150 msec after the violation point seemingly contradicts the conclusion that early and automatic syntactic analysis is restricted to structure building processes. However, the syntactic MMN paradigm differs considerably from other paradigms investigating syntax processing. It is quite possible that the controversial findings result from these paradigmatic differences. For example, the stimulus material used in the syntactic MMN paradigm is extremely well controlled for any acoustic confounds. This allows for a precise time-locking of the ERPs to the point at which the syntactic violation occurs, which benefits the detection of early ERP effects by reducing latency jitter often induced if ERPs are calculated from word onset. On the other hand, the linguistic material in syntactic MMN studies is necessarily restricted to a few short utterances that are repeated with a high frequency. Because of these restrictions, only very local syntactic dependencies can be investigated. These particular circumstances may trigger processing mechanisms that differ from those applied during the analysis of longer sentences as they

are frequently used in other studies. To make valid inferences concerning the relative timing and automaticity of syntactic structure building and morphosyntactic processes, it is, therefore, necessary to investigate these processes within the same paradigm.

The motivation of the current study was to fulfill this requirement. To this end, two experiments were conducted in which the syntactic MMN paradigm developed by Pulvermüller and Shtyrov (2003) and Shtyrov et al. (2003) was employed to directly compare local syntactic structure building and morphosyntactic processes with respect to their temporal and attentional characteristics. We constructed German word pairs that were either syntactically congruent or realized a syntactic violation. The word pairs were presented in repetitive auditory sequences suitable for the elicitation of the automatic MMN response. In Experiment 1, correct utterances were contrasted with utterances containing subject–verb agreement violations to see whether the morphosyntactic grammaticality effect on the MMN previously reported for English (Pulvermüller & Shtyrov, 2003) and Finnish (Shtyrov et al., 2003) could be replicated in German. In Experiment 2, the same participants were tested in an identical setting with equivalent stimulus material. This time, however, the subject–verb agreement violations were replaced by word category violations disrupting local syntactic structure. This adaptation extends the syntactic MMN paradigm regarding two important aspects. First, it tests the generalizability of the grammaticality effect reported by Pulvermüller and Shtyrov (2003) and Shtyrov et al. (2003) to a different syntactic structure. Second, because of a precise time-locking of the ERP responses to the violation point in both experiments, the timing and automaticity of syntactic structure building processes and morphosyntactic processes can now be directly compared.

With respect to the earlier syntactic MMN studies, the following predictions were made:

1. Because of the acoustic contrast between standard and deviant phrase, an MMN is expected to be elicited in all conditions, irrespective of the syntactic manipulations.

2. The syntactic context should modulate the amplitude of the MMN. Specifically, grammatically incorrect deviants are expected to produce larger MMN amplitudes than correct deviants. Because of the local nature of the syntactic violations, this grammaticality effect should occur for both violation types (i.e., in both experiments).

3. However, qualitative differences between processes underlying syntactic structure building and morphosyntactic processes, as suggested by the neurocognitive model of auditory sentence comprehension (Friederici, 2002), may be reflected in variations of MMN latency, amplitude, or topography as a function of violation type.

## METHODS

### Participants

The two experiments were run in a within-subject design. Twelve male and 12 female native speakers of German aged 20 to 29 years (mean age = 24.7) were paid for their participation. All were right-handed, as determined by the Edinburgh Inventory (Oldfield, 1971). The average laterality quotient was 91.67. None of the participants reported any neurological or hearing deficits.

### Stimuli

The stimulus material was constructed based on the German verb *falten* [to fold] and the noun *Falter* [butterfly]. These words were chosen because of their shared word stem and equal frequency (according to the *Wortschatz Lexikon*<sup>1</sup>). In Experiment 1, two inflected forms of the verb were combined with two personal pronouns (second and third person singular) that either syntactically matched the inflected verbform or violated subject–verb agreement (i.e., *du faltest* [you fold] vs. *\*du faltet* [\*you folds], and *er faltet* [he folds] vs. *\*er faltest* [\*he fold]). The phrase structure of all word pairs (independent of their grammatical correctness) remained constant in this experiment (i.e., subject + verb). Experiment 2 utilized the same word stem, but here the last syllable of the word was exchanged so that either the inflected verb form *faltet* or the noun *Falter* was generated. The two words were combined with either the third person singular pronoun or an indefinite article (i.e., *er faltet* [he folds] vs. *\*er Falter* [\*he butterfly] and *ein Falter* [a butterfly] vs. *\*ein faltet* [\*a folds]). In this experiment, the crossed combinations of the four words resulted in word pairs with different phrase structures. The correct word pairs either comprised a subject NP + verb or a determiner + noun combination. One incorrect word pair (*\*ein faltet*) was a determiner–verb combination that is syntactically illegal. The other incorrect word pair (*\*er Falter*), however, was a subject NP + NP combination, which is legal with respect to the German syntax as two NPs can follow each other in a sentence (e.g., “Sie weiss, dass *er Falter* sammelt” [literally: “She knows, that he butterflies collects”]). Nevertheless, the absence of a sentence context in the current setting renders the occurrence of a noun after a subject NP a highly unexpected event that is in all probability perceived as incorrect. It thus can be assumed that both incorrect word pairs induced a violation of the word category expected based on the preceding subject NP or determiner.

The MMN is elicited in response to even the slightest acoustical difference between standard and deviant stimulus. When speech stimuli are used, this is of particular concern because syntactic information might be conveyed by subtle differences in prosodic parameters

like duration, pitch, or intensity, even if the word stem is morphologically identical. In producing the utterances of the word pairs that will be presented as standard and deviant stimuli in the same MMN sequence, it is therefore of great importance to ensure that the point of the acoustic deviation coincides with the point at which the syntactic violation occurs and that any acoustic differences before that point are ruled out. Accordingly, the stimuli were produced as follows. The common word stem was embedded into a syntactically neutral context consisting of the pseudoword *lub* and the pseudosuffix *-k*. Several recordings of the resulting pseudophrase (*lub faltek*) and of the three syntactically correct combinations (*er faltet*, *du faltest*, and *ein Falter*) were taken. A trained female speaker pronounced the word pairs with natural sentence prosody. She was instructed to avoid coarticulation between the two words by inserting a short pause into the speech stream. The recordings were then digitized at a sampling rate of 44.1 kHz (16 bit; mono). The four acoustically most similar recordings were selected and normalized to the same sound intensity. The pause between the two words was adjusted to 120 msec in all cases. The invariant word stem was taken from the recording of the pseudophrase and used for all experimental stimuli. As Table 1 exemplifies, it was combined with the recordings of each of the pronouns and suffixes (Experiment 1) and the third person pronoun or indefinite article and the final syllables (Experiment 2) taken from the syntactically correct utterances by splicing together the respective waveforms. It was necessary to exchange the entire final syllable in Experiment 2 because the vowel [e] differs phonetically between the inflected verb form [ˈfaltət] and the noun [ˈfaltɐ], and coarticulation did not permit inconspicuous splicing after the preceding consonant [t].

The oscillograms of the four stimulus pairs in their final form are depicted in Figure 1. Each stimulus pair contains one grammatically correct and one incorrect

utterance. The two utterances in a pair are acoustically identical before the onset of the suffix (Experiment 1) or final syllable (Experiment 2), which marks the respective point of physical divergence between standard and deviant stimulus in the MMN sequences. In the following, this point will be referred to as the divergence point (DP). It is important to note that all speech stimuli were spliced in an equal manner, so that manipulations of the acoustic signals were not confounded in any way with the syntactic properties of the speech stimuli. The digitization of the recording and all signal manipulations were conducted using the COOL EDIT 2000 program (Syntrillium Software).

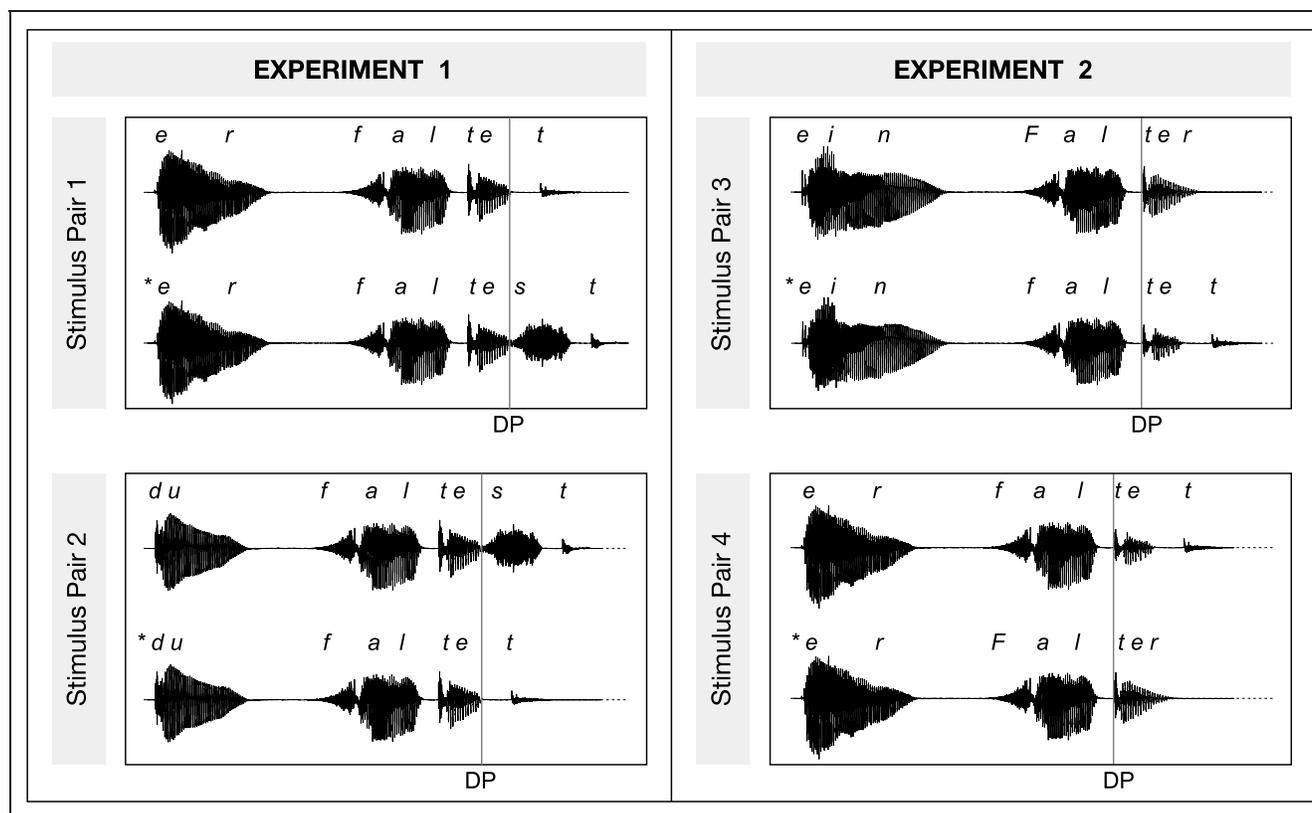
## Design and Procedure

Stimulus pairs 1 (*er faltet*/\**er faltest*) and 2 (*du faltest*/\**du faltet*) were used in Experiment 1 to investigate the automatic detection of subject–verb agreement violations. Accordingly, stimulus pairs 3 (*ein Falter*/\**ein faltet*) and 4 (*er faltet*/\**er Falter*) implemented the word category violations under investigation in Experiment 2. Each experiment comprises four sequences in which the utterances of a given stimulus pair were contrasted as standards ( $n = 750$ , 83.3%) and deviants ( $n = 150$ , 16.7%). Two sequences (A and B) were constructed from each stimulus pair. In A sequences, the grammatically correct utterance of a pair was presented as the standard stimulus, whereas the grammatically incorrect utterance served as the deviant. In B sequences, standard and deviant were interchanged. As Table 2 clarifies, this approach results in an orthogonal  $2 \times 2$  design affording the disentanglement of acoustic and syntactic influences on the MMN response. It is important to note that the impact of acoustic features is controlled for in two ways. First, the acoustic contrast between the standard and deviant stimuli in each of two sequences relevant for the grammaticality effect (i.e., sequences 1A and 2B, 1B and 2A, 3A and 4B, and 3B and 4A) is *identical*. Second, the grammaticality effect is tested in both possible directions of acoustic change. It is unclear from the literature whether the parameters of the MMN are mainly determined by the magnitude of the acoustic change (Näätänen & Alho, 1997) or whether the direction of the change exerts an influence as well, as suggested by studies showing different MMN characteristics depending on whether the acoustic deviance consisted of the inclusion or the omission of a given stimulus feature (Sabri & Campbell, 2000; Nordby, Hammerborg, Roth, & Hugdahl, 1994). With respect to the current material, it cannot be excluded that a sequence including an acoustic change in one direction (e.g., a deviant ending with *-st* presented among standards ending with *-t*) produces a larger MMN than a sequence containing the reverse case purely based on acoustic effects. To exclude the possibility that such an acoustic confound promotes the grammaticality effects under investigation,

**Table 1.** Stimulus Production

|              | Recording                                    | Experimental Stimuli                                  |
|--------------|--|---|
| Experiment 1 | lub <sub>Δ</sub> <b>falte</b> <sub>Δ</sub> k | <b>er</b> <sub>Δ</sub> <b>falte</b> <sub>Δ</sub> t    |
|              | <b>er</b> <sub>Δ</sub> falte <sub>Δ</sub> t  | * <b>er</b> <sub>Δ</sub> <b>falte</b> <sub>Δ</sub> st |
|              | <b>du</b> <sub>Δ</sub> falte <sub>Δ</sub> st | <b>du</b> <sub>Δ</sub> <b>falte</b> <sub>Δ</sub> st   |
|              |  | * <b>du</b> <sub>Δ</sub> <b>falte</b> <sub>Δ</sub> t  |
| Experiment 2 | lub <sub>Δ</sub> <b>fal</b> <sub>Δ</sub> tek | <b>er</b> <sub>Δ</sub> <b>fal</b> <sub>Δ</sub> tet    |
|              | <b>er</b> <sub>Δ</sub> fal <sub>Δ</sub> tet  | * <b>er</b> <sub>Δ</sub> <b>Fal</b> <sub>Δ</sub> ter  |
|              | <b>ein</b> <sub>Δ</sub> Fal <sub>Δ</sub> ter | <b>ein</b> <sub>Δ</sub> <b>Fal</b> <sub>Δ</sub> ter   |
|              |  | * <b>ein</b> <sub>Δ</sub> <b>fal</b> <sub>Δ</sub> tet |

The points at which the recorded speech signals were cut are indicated with Δ. The segments that were combined to form the different experimental stimuli are in bold. \*Grammatically incorrect stimuli.



**Figure 1.** Oscillograms of the experimental speech stimuli. The utterances in each stimulus pair are acoustically identical until the DP indicated by the vertical line. \*Utterances containing syntactic violations.

the direction of the acoustic change is varied independently of the grammaticality of the deviant phrases in the current design. To capture any possible influence the direction of acoustic change might still exert on the MMN, the acoustically divergent element between standard and deviant phrase in a respective sequence (i.e., the suffix in Experiment 1 and the final syllable in Experiment 2) was included as an independent factor in the statistical analysis.

The sequences were randomized with a minimum of two and a maximum of eight standards occurring between any two deviants. After randomization, 10 standard stimuli were added to the beginning of each sequence to establish the memory trace against which the deviant will be compared. The stimulus onset asynchrony was adjusted to the length of the speech signals. It was approximately 440 msec longer than the longer stimulus in each pair (pair 1: 1780 msec; pair 2: 1700 msec; pair 3: 1740 msec; pair 4: 1660 msec). This resulted in a presentation time of approximately 26 min/sequence.

Experiments 1 and 2 were conducted in separate sessions at intervals of at least 1 week. The order of the two experiments and the order of the four sequences within each session were counterbalanced across participants, with an equal number of women and men in each group. The stimulus sequences were presented

binaurally via headphones (Sennheiser HD 414) while participants were seated in a comfortable chair inside an acoustically and electrically shielded chamber. Participants were instructed to focus their attention on a silent movie and to ignore any auditory input. To reduce artifacts, they were also asked to refrain from moving, swallowing, or blinking to the greatest possible extent. Every time a sequence was completed, participants were allowed to take a break for as long as they required.

### Electrophysiological Recording

For the duration of each sequence, continuous EEGs were recorded from 58 Ag/AgCl electrodes mounted in an elastic cap (Electro Cap International). The specific locations of the electrodes were FP1/2, AF7/8, AF3/4, AFz, F9/10, F7/8, F5/6, F3/4, Fz, FT9/10, FT7/8, FC5/6, FC3/4, FCz, T7/8, C5/6, C3/4, Cz, TP9/10, TP7/8, CP5/6, CP3/4, CPz, P9/10, P7/8, P5/6, P3/4, Pz, PO7/8, PO3/4, POz, O1/2, and Oz according to the nomenclature proposed by the American Electroencephalographic Society (Sharbrough, 1991). Additional electrodes were placed at left and right mastoid positions and at the nose, with the latter serving as the on-line reference. The ground electrode was placed at the sternum. The signals were sampled at 500 Hz. An anti-aliasing filter of 135 Hz was applied during recording. To control for eye-

**Table 2.** Experimental Design

|              | <i>Sequence</i> | <i>Standard</i>                    | <i>Deviant</i>                     | <i>Factor Level</i>                 |
|--------------|-----------------|------------------------------------|------------------------------------|-------------------------------------|
| Experiment 1 | 1A              | <i>er falte-t</i> [he folds]       | <i>*er falte-st</i> [*he fold]     | Gram = incorrect<br>De = st         |
|              | 1B              | <i>*er falte-st</i> [*he fold]     | <i>er falte-t</i> [he folds]       | Gram = correct<br>De = t            |
|              | 2A              | <i>du falte-st</i> [you fold]      | <i>*du falte-t</i> [*you folds]    | Gram = incorrect<br>De = t          |
|              | 2B              | <i>*du falte-t</i> [*you folds]    | <i>du falte-st</i> [you fold]      | Gram = correct<br>De = st           |
| Experiment 2 | 3A              | <i>ein Fal-ter</i> [a butterfly]   | <i>*ein fal-tet</i> [*a folds]     | Gram = incorrect<br>De = tet (verb) |
|              | 3B              | <i>*ein fal-tet</i> [*a folds]     | <i>ein Fal-ter</i> [a butterfly]   | Gram = correct<br>De = ter (noun)   |
|              | 4A              | <i>er fal-tet</i> [he folds]       | <i>*er Fal-ter</i> [*he butterfly] | Gram = incorrect<br>De = ter (noun) |
|              | 4B              | <i>*er Fal-ter</i> [*he butterfly] | <i>er fal-tet</i> [he folds]       | Gram = correct<br>De = tet (verb)   |

German auditory language stimuli are in italic. The acoustic contrast between standards and deviants is in bold. \*Utterances containing syntactic violations. English translations are given in brackets. The level of the condition factors corresponds to the deviant stimulus.

Gram = grammaticality, De = divergent element.

movement artifacts, bipolar horizontal and vertical electrooculograms were calculated from monopolar recordings of electrode pairs positioned at the outer canthus of each eye and above and below the right eye, respectively. All electrode impedances were kept below 5 k $\Omega$  throughout the recording.

### Data Processing and Statistical Analyses

The EEG channels were rereferenced off-line to the arithmetic mean of the mastoid recordings. A semiautomatic artifact rejection procedure was applied to the continuous data. First, an automatic rejection criterion (voltage variation of more than 40  $\mu$ V within a 200-msec sliding time window) was applied to the electrooculogram channels and electrode Cz to mark trials contaminated by eye-movement artifacts. In a second step, all channels were scanned manually for any additional disturbances. The continuous recordings were then cut into epochs ranging from 100 msec pre-DP to 600 msec post-DP, with the 100-msec pre-DP serving as the baseline. Average ERPs were computed separately for each participant, experiment, condition, and stimulus type. Epochs containing artifacts or representing standard stimuli directly following deviant stimuli were excluded. The mean number of epochs entering the single subject averages is listed for each experiment, sequence,

and stimulus type in Table 3. To evaluate the MMN, difference waves were calculated within each sequence by subtracting the averaged ERP to the standard stimulus from that to the respective deviant stimulus. All further analysis steps were conducted on the difference waves.

To account for the topographical distribution of the ERPs in the statistical analyses, the scalp surface was divided into four quadrants of nine electrodes each: Left anterior (FP1, AF3, AF7, F3, F5, F7, FC3, FC5, and FT7),

**Table 3.** Number (Mean  $\pm$  SD) of Averaged Trials for Each Experiment, Condition, and Stimulus Type

|              | <i>Sequence</i> | <i>Standard</i> | <i>Deviant</i> | <i>Total</i> |
|--------------|-----------------|-----------------|----------------|--------------|
| Experiment 1 | 1A              | 466 $\pm$ 49    | 114 $\pm$ 16   | 580 $\pm$ 63 |
|              | 1B              | 477 $\pm$ 56    | 117 $\pm$ 16   | 594 $\pm$ 71 |
|              | 2A              | 477 $\pm$ 48    | 118 $\pm$ 12   | 594 $\pm$ 59 |
|              | 2B              | 482 $\pm$ 51    | 119 $\pm$ 13   | 601 $\pm$ 64 |
| Experiment 2 | 3A              | 474 $\pm$ 42    | 118 $\pm$ 10   | 592 $\pm$ 50 |
|              | 3B              | 474 $\pm$ 42    | 119 $\pm$ 11   | 593 $\pm$ 52 |
|              | 4A              | 475 $\pm$ 45    | 119 $\pm$ 14   | 594 $\pm$ 58 |
|              | 4B              | 486 $\pm$ 44    | 119 $\pm$ 10   | 605 $\pm$ 53 |

right anterior (FP2, AF4, AF8, F4, F6, F8, FC4, FC6, and FT8), left posterior (CP3, CP5, TP7, P3, P5, P7, PO3, PO7, and O1), and right posterior (CP4, CP6, TP8, P4, P6, P8, PO4, PO8, and O2). To assess whether the acoustic difference between standard and deviant stimulus elicited reliable MMN responses, time windows of 100 msec centered on the first clear negative peak were defined for each experiment by visual inspection of the grand average data. The mean amplitudes in the MMN time windows were calculated for each sequence and topographical quadrant and compared with zero using paired two-tailed *t* tests. After this initial MMN quantification procedure, the impact of the linguistic manipulations on the mean amplitude of the difference waves in each experiment was assessed for the entire epoch using repeated measure analyses of variance (ANOVAs). They included the two topographical factors Hemisphere (left vs. right) and Region (anterior vs. posterior) as well as the two condition factors Grammaticality (correct vs. incorrect) and Divergent Element (*-st* vs. *-t* for Experiment 1 and *-tet* vs. *-ter* for Experiment 2), which were assigned according to the properties of the deviant stimulus (see Table 2). The time windows for mean amplitude calculation were defined as follows. First, the epoch was divided into nonoverlapping sections of 20 msec, which were subjected to ANOVA. This preliminary timeline analysis allowed for an objective and reasonably exact definition of the onsets and durations of the effects. If at least marginally significant effects ( $p < .1$ ) involving a condition factor persisted for three or more consecutive sections, these were merged, and the ANOVA was repeated on the resulting larger time windows. Only the outcome of this second analysis step is reported. If an interaction including at least one of the condition factors reached significance ( $p \leq .05$ ), it was resolved with respect to the condition factor(s). Main effects or interactions including only topographical factors are not reported.

## RESULTS

Figure 2A shows the grand average difference waveforms at electrode FCz, where the MMN is usually largest. The difference waveforms were obtained for each sequence by subtracting the averaged ERP to the standard stimuli from the averaged ERP to the deviant stimuli. Waveforms from each of two sequences for which the acoustic contrasts were identical but the grammaticality was reversed (e.g., sequence 1A and 2B) are plotted together. Visual inspection of the data reveals a prominent early negativity after approximately 100 msec, which is present in all waveforms. This negativity appears to be enhanced for sequences in which the deviant was grammatically incorrect (depicted in red), although this effect appears to be reduced for the highly unexpected but syntactically legal subject NP + NP condition in Experiment 2. Figure 2B presents topographical maps that

show the scalp distribution of the electrical activity in the time window of the grammaticality effect. In Experiment 2, the early negativity additionally seems to be modulated by the respective divergent element. It is much more pronounced if the deviant phrase ended with *-tet* than when it ended with *-ter*. Furthermore, its onset appears to be slightly delayed as compared with Experiment 1. In the following, the results of the MMN quantification procedure and ANOVAs are reported separately for each experiment. Statistical values and effect sizes are listed in Tables 4 and 5 for Experiment 1 and in Tables 6 and 7 for Experiment 2.

## Experiment 1: Subject-Verb Agreement Violation

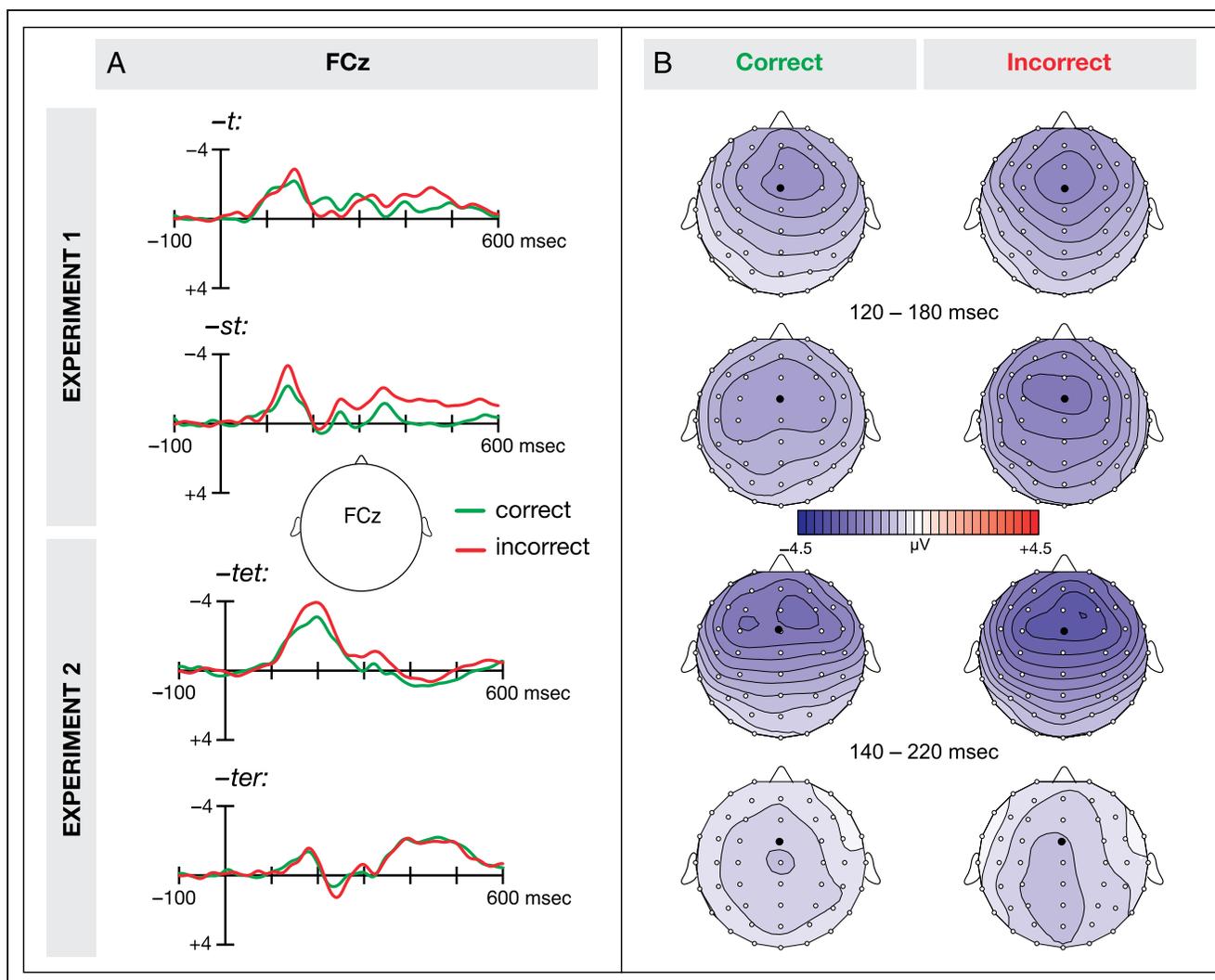
### *Mismatch Negativity Quantification*

For Experiment 1, the MMN time window was set to 100 to 200 msec. Paired *t* tests conducted on the mean amplitude of each topographical quadrant confirmed that the observed negativities in this time window differed significantly from zero (see Table 4). The mean amplitude values show that the negativity was largest over the anterior half of the scalp in all cases, which is consistent with the usually reported MMN topography. It can therefore be concluded that each of the sequences in Experiment 1 produced a significant MMN response.

### *Analysis of Variance*

Based on the results of the preliminary timeline analysis, effects of the condition factors on the MMN amplitude were assessed in a time window of 60 msec surrounding the MMN peak (120–180 msec). A significant main effect of Grammaticality indicates larger MMN amplitudes for sequences containing grammatically incorrect deviants than for sequences containing correct deviants. A significant Hemisphere  $\times$  Region  $\times$  Grammaticality interaction reveals that this effect is strongest over left anterior scalp regions. Over the left hemisphere, the MMN further shows significantly increased amplitudes in response to deviants ending with *-st* as opposed to deviants ending with *-t*, as indicated by a significant Hemisphere  $\times$  Divergent Element interaction in this early time window.

For the remaining epoch, the ANOVA reveals two more significant effects. First, the type of suffix has a significant impact between 180 and 240 msec. A highly significant Region  $\times$  Divergent Element interaction reveals that over anterior sites, the difference waves are now significantly more positive when the deviant ended with *-st* than when it ended with *-t*. Second, a somewhat more sustained negativity for the sequences containing grammatically incorrect deviants is reflected in a significant main effect for Grammaticality between 300 and 500 msec.



**Figure 2.** (A) Difference waves (deviant – standard) at electrode FCz for the four sequences in each experiment. Waveforms resulting from sequences with identical acoustical contrasts but reversed grammaticality are plotted together. A 10-Hz low-pass filter was applied for display purposes only. (B) Topographical maps corresponding to each of the waveforms in (A) for the time window of the grammaticality effect. The black spot indicates the position of electrode FCz.

## Experiment 2: Word Category Violation

### Mismatch Negativity Quantification

Because of the slightly delayed onset of the negativities in Experiment 2, the MMN time window was adjusted to 120 to 220 msec. The paired *t* test conducted on the mean amplitudes in this time window confirms the visual impression that the characteristics of the negativities differ depending on the respective divergent element of a sequence. For sequences in which the deviant ends with the syllable *-tet*, the mean amplitude greatly differs from zero in all four topographical quadrants, and the negativity shows the anterior focus also observed in Experiment 1. If the deviant ends with the syllable *-ter*, however, the negativity is significant over posterior scalp sites only, which poses a rather untypical distribution for an MMN response.

### Analysis of Variance

Effects of the condition factors on the MMN amplitude were assessed in a time window of 80 msec surrounding the MMN peak (140–220 msec). As in Experiment 1, this time window was defined based on the preliminary 20-msec timeline analysis. Confirming the observations from the plots and the MMN quantification procedure, a highly significant main effect of Divergent Element reveals greatly enhanced MMN amplitudes to deviants ending with *-tet* as opposed to deviants ending with *-ter*. Additionally, a main effect of Grammaticality shows that as in Experiment 1, MMN amplitudes were larger for sequences with grammatically incorrect deviants than for sequences with correct deviants. However, the effect appeared to have a different topographical distribution than in Experiment 1. Break down analyses of a marginally

**Table 4.** MMN Quantification Experiment 1: 100 to 200 msec

| Sequence | Deviant              | Q  | Mean      |         |              |
|----------|----------------------|----|-----------|---------|--------------|
|          |                      |    | Amplitude | t Value | p Value      |
| 1A       | incorrect <i>-st</i> | LA | -1.42     | -8.03   | <.0001       |
|          |                      | RA | -1.25     | -6.45   | <.0001       |
|          |                      | LP | -1.11     | -5.74   | <.0001       |
|          |                      | RP | -1.16     | -5.85   | <.0001       |
| 1B       | correct <i>-t</i>    | LA | -1.14     | -6.47   | <.0001       |
|          |                      | RA | -1.42     | -7.11   | <.0001       |
|          |                      | LP | -0.29     | -1.79   | <b>.0859</b> |
|          |                      | RP | -0.55     | -3.26   | <.01         |
| 2A       | incorrect <i>-t</i>  | LA | -1.44     | -7.64   | <.0001       |
|          |                      | RA | -1.54     | -7.84   | <.0001       |
|          |                      | LP | -0.53     | -3.39   | <.01         |
|          |                      | RP | -0.61     | -5.04   | <.0001       |
| 2B       | correct <i>-st</i>   | LA | -0.92     | -5.00   | <.0001       |
|          |                      | RA | -1.04     | -6.61   | <.0001       |
|          |                      | LP | -0.83     | -5.62   | <.0001       |
|          |                      | RP | -0.80     | -4.82   | <.0001       |

Nonsignificant *p* values are in bold.

Q = Quadrant; LA = left anterior; RA = right anterior; LP = left posterior; RP = right posterior.

significant Hemisphere  $\times$  Region  $\times$  Grammaticality interaction ( $p = .051$ ) revealed significant effects of Grammaticality in all but the left anterior quadrant. Contrary to the visual impression of a reduced effect for the unexpected but syntactically legal subject NP + NP condition, the interaction of Divergent Element and Grammaticality failed to reach significance ( $p = .14$ ).

ANOVAs conducted on the time windows after the MMN revealed a second main effect for Grammaticality between 280 and 360 msec, where the difference waves were again more negative for sequences containing incorrect deviants. A prominent late negativity for sequences in which the deviants ended with *-ter* was reflected in a significant main effect of Divergent Element in the time range from 360 to 600 msec.

## DISCUSSION

The two experiments of the present study contrasted morphosyntactic and word category violations implemented in two-word utterances in a syntactic MMN paradigm. As the acoustic properties of the speech stimuli were thoroughly controlled for, it was possible to assess the impact of the applied syntactic manipulations on the MMN response in isolation. The results can be summarized as follows.

The acoustic contrasts between the standard and deviant stimuli reliably elicited an MMN in all presented sequences. The amplitude and topography of this automatic brain response were modulated by the experimental manipulations in both experiments. In accordance with our hypotheses, MMN amplitudes were larger in sequences in which the deviant was grammatically incorrect than when it was grammatically correct. Importantly, this effect was present for both morphosyntactic and phrase structure violations, but differed in topographical distribution depending on the violation type. An additional finding in the MMN time range was the modulating effect of the respective divergent element in the two experiments. The inflectional suffix indicating subject–verb agreement had a differential effect on the MMN amplitude over the left hemisphere, where it was larger when the deviant stimulus ended with *-st* than when it ended with *-t*. This effect was followed by a stronger positivity in response to *-st* deviants. The suffix indicating word category greatly affected both the amplitude and the topography of the MMN, inasmuch as the deviant syllable *-ter*, which disambiguates the second word of the utterance toward a noun, elicited a much reduced and unusually posteriorly distributed MMN as compared with the verb-ending syllable *-tet*. It is, however, important to note that although the nature of the acoustic contrast did affect MMN amplitudes, there were no significant interactions between the two condition factors, Divergent Element and Grammaticality, in either of the experiments. It can thus be concluded that the observed grammaticality effects could not be based on the acoustic contrast between standard and deviant stimuli alone.

Analyses of the time range after the MMN revealed a second grammaticality related negativity around 300 msec in both experiments and an extended effect of the divergent syllable between 360 and 600 msec in Experiment 2. In the following, the obtained effects will be discussed in detail with regard to possible underlying brain mechanisms and implications for the temporal and structural specificity of the syntactic processes involved.

## Grammaticality Effects

The amplitude of the MMN was modulated by the grammaticality of the deviant stimulus in both experiments. In Experiment 1, the subject–verb agreement violations caused enhanced MMN amplitudes over left anterior scalp sites. This effect constitutes a German replication of the “syntactic MMN” reported by Pulvermüller and Shtyrov (2003) and Shtyrov et al. (2003) for agreement violations in English and Finnish and confirms that under the given experimental circumstances, morphosyntactic violations are indeed detected at this early automatic stage of processing. Experiment 2 extends these findings by showing that the MMN is equally

**Table 5.** ANOVA Results of Experiment 1

| Factors               | 120–180 msec (MMN) |          | 180–240 msec    |          | 300–500 msec    |          |
|-----------------------|--------------------|----------|-----------------|----------|-----------------|----------|
|                       | <i>F</i> (1,23)    | $\Delta$ | <i>F</i> (1,23) | $\Delta$ | <i>F</i> (1,23) | $\Delta$ |
| DE                    | 2.19               |          | 2.57            |          | <1              |          |
| Gram                  | 5.71*              | 0.4      | <1              |          | 11.41**         | 0.5      |
| Hem × DE              | 5.63*              |          | <1              |          | <1              |          |
| DE (LH)               | 4.71*              | 0.4      |                 |          |                 |          |
| DE (RH)               | <1                 |          |                 |          |                 |          |
| Reg × DE              | 4.08               |          | 38.72****       |          | <1              |          |
| DE (ant)              |                    |          | 16.78***        | 0.8      |                 |          |
| DE (post)             |                    |          | 1.70            |          |                 |          |
| Hem × Gram            | 1.13               |          | 4.46*           |          | <1              |          |
| Gram (LH)             |                    |          | <1              |          |                 |          |
| Gram (RH)             |                    |          | <1              |          |                 |          |
| Reg × Gram            | <1                 |          | 1.47            |          | 1.22            |          |
| DE × Gram             | <1                 |          | 1.27            |          | <1              |          |
| Hem × Reg × DE        | <1                 |          | <1              |          | 1.46            |          |
| Hem × Reg × Gram      | 5.82*              |          | <1              |          | <1              |          |
| Gram (LH/ant)         | 6.97*              | 0.5      |                 |          |                 |          |
| Gram (LH/post)        | 3.34               |          |                 |          |                 |          |
| Gram (RH/ant)         | 3.00               |          |                 |          |                 |          |
| Gram (RH/post)        | 3.83               |          |                 |          |                 |          |
| Hem × DE × Gram       | <1                 |          | <1              |          | <1              |          |
| Reg × DE × Gram       | <1                 |          | <1              |          | <1              |          |
| Hem × Reg × DE × Gram | 1.89               |          | <1              |          | <1              |          |

$\Delta$  = Effect size ( $\mu$ V); DE = Divergent Element; Hem = Hemisphere; Reg = Region; Gram = Grammaticality; LH = left hemisphere; RH = right hemisphere; ant = anterior; post = posterior.

\* $p < .05$ .

\*\* $p < .01$ .

\*\*\* $p < .001$ .

\*\*\*\* $p < .0001$ .

sensitive to the detection of word category violations. Although one of the incorrect word pairs in this experiment (i.e., *\*er Falter*) constituted a highly unexpected formation rather than an outright word category violation, the statistical analysis resulted in a main effect of grammaticality only. This allows for the conclusion that the subject NP + NP construction was perceived as a violation in the current setting, although an adumbrated interaction between grammaticality and divergent element as well as the visual impression of the grand average data suggests a reduction of the grammaticality effect in this condition. The slightly delayed onset of the effect as compared with Experiment 1 is probably due to the fact that the first phoneme of the

divergent element (i.e., [t]), which has a duration of approximately 20 msec, is the same for standard and deviant utterances. Therefore, the grammatical violation does not become apparent before the discriminating vowel (i.e., [ə] vs. [ɐ]).

Across the two experiments, it thus can be said that the syntactic violations were detected automatically within 200 msec. This finding, which suggests a similarly fast and automatic detection mechanism for the different types of syntactic violations, stands in contrast to a large number of earlier studies reporting differences in the latency and automaticity of syntactic structure building and morphosyntactic processes when more complex sentence material was used (see Friederici, 2002). With

**Table 6.** MMN Quantification Experiment 2: 120–220 msec

| Sequence | Deviant               | Q  | Mean      |         |              |
|----------|-----------------------|----|-----------|---------|--------------|
|          |                       |    | Amplitude | t Value | p Value      |
| 3A       | incorrect <i>-tet</i> | LA | −2.29     | −12.17  | <.0001       |
|          |                       | RA | −2.52     | −12.06  | <.0001       |
|          |                       | LP | −1.18     | −7.46   | <.0001       |
|          |                       | RP | −1.28     | −7.95   | <.0001       |
| 3B       | correct <i>-ter</i>   | LA | −0.43     | −2.04   | <b>.0534</b> |
|          |                       | RA | −0.29     | −1.24   | <b>.2288</b> |
|          |                       | LP | −0.51     | −3.25   | <.01         |
|          |                       | RP | −0.42     | −3.79   | .001         |
| 4A       | incorrect <i>-ter</i> | LA | −0.35     | −1.84   | <b>.0789</b> |
|          |                       | RA | −0.36     | −1.60   | <b>.1238</b> |
|          |                       | LP | −0.54     | −3.54   | <.01         |
|          |                       | RP | −0.60     | −4.01   | <.001        |
| 4B       | correct <i>-tet</i>   | LA | −2.04     | −9.37   | <.0001       |
|          |                       | RA | −2.07     | −9.15   | <.0001       |
|          |                       | LP | −0.89     | −5.98   | <.0001       |
|          |                       | RP | −0.82     | −4.48   | <.001        |

Nonsignificant *p* values are in bold.

Q = Quadrant; LA = left anterior; RA = right anterior; LP = left posterior; RP = right posterior.

respect to the timing of the effects, differences in the time-locking of the ERPs may be one reason for these divergent findings. It has been pointed out that the latency of the syntactic structure building effect varies as a function of the violation point if ERPs are time-locked to the onset of the critical word. When the word category (and thus the violation) is identifiable in the prefix, the effect occurs early, but it occurs late when the violation is induced by the suffix (Friederici, Gunter, Hahne, & Mauth, 2004; Friederici et al., 1996). Because morphosyntactic violations are usually realized by changes in the suffix, time-locking of ERPs to the word onset as applied in the majority of studies could accordingly cause an artificial delay of the syntactic effects. To our knowledge, the syntactic MMN studies by Pulvermüller and Shtyrov (2003) and Shtyrov et al. (2003) as well as the present study are the only instances avoiding this problem by time-locking ERPs to morphosyntactic violations to the critical morpheme.

Other reasons for the early latency and automaticity of the current effects may be sought in the properties of the stimulus material. The local character of the syntactic violations and the frequent repetition of the short utterances in the MMN sequences reduce syntactic analysis to a match or mismatch of merely two linguistic elements. In Experiment 1, the preceding

personal pronoun evokes the expectation of a matching suffix. Likewise, encountering a pronoun or an article in Experiment 2 builds up expectations toward the word category of the following word. The syntactic context thus modulates the processing of the divergent element eliciting the MMN response, in the sense that grammatically correct elements are primed, whereas grammatically incorrect elements are not. We therefore consider the notion of *syntactic priming*, as it has been put forward by early behavioral (e.g., Goodman et al., 1981) as well as more recent electrophysiological studies (Pulvermüller & Shtyrov, 2003; Shtyrov et al., 2003) most suitable for explaining the enhanced MMN amplitudes in response to both subject–verb agreement and word category violations.

However, assuming syntactic priming as a common mechanism underlying the grammaticality effects in the two experiments does not readily explain the topographical differences between these effects. The grammaticality effect in response to the subject–verb agreement violations in Experiment 1 had its focus over the left anterior quadrant. This finding is reminiscent of the left anterior negativities (ELAN/LAN) frequently observed in response to syntactic violations in other paradigms (Coulson et al., 1998; Friederici et al., 1993, 1996; Neville et al., 1991). Furthermore, it appears plausible with respect to studies reporting enhanced activity in left frontal cortex in relation to syntax processing as investigated with morphosyntactic violations (Pulvermüller & Shtyrov, 2003; Ni et al., 2000) as well as phrase structure violations (Friederici & Kotz, 2003; Friederici, Rüschemeyer, Hahne, & Fiebach, 2003; Friederici, Wang, Herrmann, Maess, & Oertel, 2000). Based on this evidence, it is conceivable that the enhanced MMN amplitude in response to incorrect deviants represents an additive effect of the simultaneously occurring acoustic and syntactic deviance. Such an effect was shown by Hahne, Schröger, and Friederici (2002), who combined violations of syntactic structure with a physical deviation realized as a switch in location. In the present case, however, in which simultaneous deviations occur within the language modality, it may well be that the amplitude enhancement to incorrect deviants is produced by an MMN-intrinsic mechanism as suggested by Pulvermüller and Shtyrov (2003) and Shtyrov et al. (2003). In contrast to the left anterior focus in Experiment 1, the rather whole-headed distribution of the effect following the word category violations in Experiment 2 appears counterintuitive according to previous evidence. However, as reported by Friederici et al. (2000, 2003), generators supporting phrase structure processing are not exclusively left frontal but also extensive in the superior temporal cortices of both hemispheres. We would like to suggest that the distribution of the grammaticality effect in Experiment 2 is mainly driven by these temporal generators, which may reflect processes of template matching (as the incoming item is matched against the template of the local phrase

**Table 7.** ANOVA Results of Experiment 2

| Factors               | 140–220 msec (MMN) |          | 280–360 msec    |          | 360–600 msec    |          |
|-----------------------|--------------------|----------|-----------------|----------|-----------------|----------|
|                       | <i>F</i> (1,23)    | $\Delta$ | <i>F</i> (1,23) | $\Delta$ | <i>F</i> (1,23) | $\Delta$ |
| DE                    | 38.83****          | 1.3      | <1              |          | 16.29***        | 0.8      |
| Gram                  | 9.46**             | 0.3      | 8.56**          | 0.3      | 3.77            |          |
| Hem × DE              | 3.41               |          | <1              |          | <1              |          |
| Reg × DE              | 50.05****          |          | 5.13*           |          | <1              |          |
| DE (ant)              | 52.45****          | 2.1      | 1.07            |          |                 |          |
| DE (post)             | 8.95**             | 0.5      | <1              |          |                 |          |
| Hem × Gram            | <1                 |          | <1              |          | 3.61            |          |
| Reg × Gram            | <1                 |          | <1              |          | <1              |          |
| DE × Gram             | 2.33               |          | <1              |          | <1              |          |
| Hem × Reg × DE        | 1.5                |          | 2.01            |          | 2.96            |          |
| Hem × Reg × Gram      | 4.23 <sup>†</sup>  |          | <1              |          | <1              |          |
| Gram (LH/ant)         | 1.46               |          |                 |          |                 |          |
| Gram (LH/post)        | 4.81*              | 0.3      |                 |          |                 |          |
| Gram (RH/ant)         | 5.35*              | 0.3      |                 |          |                 |          |
| Gram (RH/post)        | 6.40*              | 0.3      |                 |          |                 |          |
| Hem × DE × Gram       | <1                 |          | <1              |          | <1              |          |
| Reg × DE × Gram       | <1                 |          | <1              |          | <1              |          |
| Hem × Reg × DE × Gram | <1                 |          | 2.43            |          | <1              |          |

$\Delta$  = Effect size ( $\mu V$ ); DE = Divergent Element; Hem = Hemisphere; Reg = Region; Gram = Grammaticality; LH = left hemisphere; RH = right hemisphere; ant = anterior; post = posterior.

\* $p < .05$ .

\*\* $p < .01$ .

\*\*\* $p < .001$ .

\*\*\*\* $p < .0001$ .

<sup>†</sup> $p \approx .051$ .

structure) rather than the left frontal, syntactic–relational processes apparently triggered in Experiment 1. The exact localization of the processes underlying the currently observed distributions certainly needs to be substantiated by future research. Nevertheless, the fact that the distribution clearly differs in the two experiments strongly suggests a functional separation of morphosyntactic processes and processes of syntactic structure building even at the earliest automatic level of processing.

After the MMN, a second grammaticality related negativity occurred in both experiments. Although a similarly biphasic pattern of the syntactic MMN response was reported before (Pulvermüller & Shtyrov, 2003), the underlying function of this second negativity is yet unclear. It is conceivable that it reflects a higher order process identifying the syntactic violation, as opposed to the basic syntactic priming effect reflected in the earlier MMN amplitude modulation. Further research will be

needed to provide a less speculative interpretation of this effect.

### Divergent Element Effects

The divergent element between the stimuli in a sequence had a significant impact on the amplitude of the MMN responses in both experiments. In Experiment 1, sequences in which the deviant ended with *-st* produced larger MMN amplitudes than sequences including deviants ending with *-t*. This effect was lateralized to the left hemisphere and followed by a stronger positivity for *-st* deviants over anterior sites. In Experiment 2, the divergent final syllable of the phrases affected the amplitude as well as the topography of the MMN responses. Sequences in which the syllable *-ter* disambiguated the second word of the deviant phrase toward a noun produced smaller MMNs with a

rather untypical posterior distribution. Furthermore, the waveforms resulting from these sequences display a second prominent negativity between 360 and 600 msec (see Figure 2).

These unanticipated findings can be interpreted in two fundamentally different ways. First, they could be attributed to differences in the mere acoustic features of the respective divergent elements (i.e., differences in pitch, duration, and/or intensity). As pointed out above, it cannot be excluded that the *direction* of the acoustic contrast affects the MMN amplitude even if the *magnitude* of the acoustic contrast is identical. Along these lines, it is conceivable that the deviance caused by a phrase ending with the suffix *-st* presented among standard phrases ending with *-t* is more salient than that caused by a phrase ending with *-t* in the reverse scenario because a phoneme is added in the former case and omitted in the latter. Likewise, it is possible that the stop consonant [t] in the syllable *-tet* pops out more easily than the schwa-sound in the syllable *-ter*.

However, such a pure acoustic interpretation appears to have several shortcomings. Neither can it account for the specific topography of the divergent element effects in the two experiments nor does it provide an explanation for the second negativity in response to deviants ending with *-ter* in Experiment 2. These two instances rather point toward a possible involvement of linguistic features induced by the respective divergent element. In Experiment 1, where two inflectional suffixes were contrasted, the effect of the divergent element on the MMN became manifest over the left hemisphere only, which suggests an involvement of language-related areas. Especially against the background of an earlier study, which investigated the processing of inflectional affixes by means of the MMN and reported a similarly left-lateralized effect (Shtyrov & Pulvermüller, 2002), the possibility that the MMN could actually be capable of reflecting the automatic processing of inflectional morphology does not seem so unlikely. In Experiment 2, the divergent element affected both amplitude and topography of the MMN in an even more striking way. Here, the divergent element disambiguates the utterance's second word either to the noun *Falter* [butterfly] or to the inflected verb form *faltet* [folds], thus inducing a switch in word category between standard and deviant stimulus. According to the neurocognitive model of auditory sentence comprehension (Friederici & Kotz, 2003; Friederici, 2002), word category information is accessed very early and automatically as a primary step in syntactic analysis. Furthermore, there is pervasive evidence from neuropsychological, psychophysiological, and neuroimaging studies suggesting representational differences between verbs and nouns (e.g., Federmeier, Segal, Lombrozo, & Kutas, 2000; Perani et al., 1999; Damasio & Tranel, 1993), although it is still unclear what the basis of these might be, because the two-word categories differ with

respect to a variety of factors including syntactic role and semantic content (for a review, see Shapiro & Caramazza, 2003). In fact, the finding that the MMN in response to deviants containing the noun *Falter* is unusually posteriorly distributed is consistent with a wide range of studies linking the processing of verbs to prefrontal and the processing of nouns to temporo-occipital regions (Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2001; Pulvermüller, Mohr, & Schleicher, 1999; Daniele, Giustolisi, Silveri, Colosimo, & Gianotti, 1994; Damasio & Tranel, 1993). Under these premises, there is no reason why word category information should not modulate the characteristics of the MMN responses in Experiment 2, either based on syntactic or even semantic features of the specific two items contrasted here. Differences in the semantic stimulus features might further account for the unexpected negativity observed in response to noun deviants between 360 and 600 msec, because the latency and topography of this effect strongly resemble a well-studied centroparietal ERP component known to reflect semantic integration processes (i.e., the "N400") (Kutas & Hillyard, 1980; for a review, see Kotz & Friederici, 2003).

In summary, we think that an interpretation in terms of linguistic features is better able to account for the specific characteristics of the divergent element effects on the MMN response in the two experiments than an interpretation based on acoustic features alone. However, because the impact of linguistic features cannot be disentangled from the impact of acoustic features in the current design, this interpretation needs to remain tentative and awaits further investigations.

## Conclusions

The current study provides evidence for the early and automatic detection of both phrase structure and morphosyntactic violations implemented in acoustically controlled two-word utterances. The automatic MMN response of the brain was shown to be modulated by both of these violation types, a finding that was interpreted in terms of a syntactic priming effect. Importantly, the topographical distribution of this effect varied as a function of the violation type, which suggests a functional separation of syntactic structure building and morphosyntactic processes even at the earliest automatic level of sentence analysis. This finding is in accordance with the neurocognitive model of auditory sentence comprehension (Friederici & Kotz, 2003; Friederici, 2002). However, the assumed temporal sequentiality of these processes could not be confirmed by the present data, which show that the timing of syntactic ERP effects is greatly influenced by methodological factors such as the precision of time-locking (i.e., word onset vs. violation point) or the linguistic complexity of the presented stimulus material (i.e., longer sentences vs. two-word utterances).

## Acknowledgments

The authors thank Heike Böthel for her help during data acquisition, as well as Korinna Eckstein, Amelie Mahlstedt, and two anonymous reviewers for their valuable comments on earlier versions of the manuscript.

Reprint requests should be sent to Anna S. Hasting, Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, 04103 Leipzig, Germany, or via e-mail: [hasting@cbs.mpg.de](mailto:hasting@cbs.mpg.de).

## Note

1. The *Wortschatz Lexikon* is a corpus that is permanently updated using publicly available texts. It was developed and is maintained by the Department of Computer Science of the University of Leipzig and can be accessed at <http://www.wortschatz.uni-leipzig.de>.

## REFERENCES

- Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain responses to morphosyntactic violations. *Language and Cognitive Processes, 13*, 21–58.
- Damasio, A. R., & Tranel, D. (1993). Nouns and verbs are retrieved with differently distributed neural systems. *Proceedings of the National Academy of Sciences, U.S.A., 90*, 4957–4960.
- Daniele, A., Giustolisi, L., Silveri, M. C., Colosimo, C., & Gainotti, G. (1994). Evidence for a possible neuroanatomical basis for lexical processing of nouns and verbs. *Neuropsychologia, 32*, 1325–1341.
- Deutsch, A., & Bentin, S. (1994). Attention mechanisms mediate the syntactic priming effect in auditory word identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 595–607.
- Federmeier, K. D., Segal, J. B., Lombrozo, T., & Kutas, M. (2000). Brain responses to nouns, verbs and class ambiguous words in context. *Brain, 123*, 2552–2566.
- Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences, 6*, 78–84.
- Friederici, A. D., Gunter, T. C., Hahne, A., & Mauth, K. (2004). The relative timing of syntactic and semantic processes in sentence comprehension. *NeuroReport, 15*, 165–169.
- Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). Temporal structure of syntactic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1219–1248.
- Friederici, A. D., & Kotz, S. A. (2003). The brain basis of syntactic processes: Functional imaging and lesion studies. *Neuroimage, 20*, S8–S17.
- Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research, 1*, 183–192.
- Friederici, A. D., Rüschemeyer, S.-A., Hahne, A., & Fiebach, C. J. (2003). The role of left inferior frontal and superior temporal cortex in sentence comprehension: Localizing syntactic and semantic processes. *Cerebral Cortex, 13*, 170–177.
- Friederici, A. D., Wang, Y., Herrmann, C. S., Maess, B., & Oertel, U. (2000). Localization of early syntactic processes in frontal and temporal cortical areas: A magnetoencephalographic study. *Human Brain Mapping, 11*, 1–11.
- Frisch, S., Schlesewsky, M., Saddy, D., & Alpermann, A. (2002). The P600 as an indicator of syntactic ambiguity. *Cognition, 85*, B83–B92.
- Goodman, G. O., McClelland, J. L., & Gibbs, R. W. (1981). The role of syntactic context in word recognition. *Memory & Cognition, 9*, 580–586.
- Gunter, T. C., & Friederici, A. D. (1999). Concerning the automaticity of syntactic processing. *Psychophysiology, 36*, 126–137.
- Gunter, T. C., Stowe, L. A., & Mulder, G. (1997). When syntax meets semantics. *Psychophysiology, 34*, 660–676.
- Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP-measure of syntactic processing. *Language and Cognitive Processes, 8*, 439–483.
- Hahne, A., & Friederici, A. D. (1999). Electrophysiological evidence for two steps in syntactic analysis: Early automatic and late controlled processes. *Journal of Cognitive Neuroscience, 11*, 194–205.
- Hahne, A., & Friederici, A. D. (2002). Differential task effects on semantic and syntactic processes as revealed by ERPs. *Cognitive Brain Research, 13*, 339–356.
- Hahne, A., Schröger, E., & Friederici, A. D. (2002). Segregating early physical and syntactic processes in auditory sentence comprehension. *NeuroReport, 13*, 305–309.
- Kaan, E., Harris, A., Gibson, E., & Holcomb, P. J. (2000). The P600 as an index of integration difficulty. *Language and Cognitive Processes, 15*, 159–201.
- Kotz, S. A., & Friederici, A. D. (2003). Electrophysiology of normal and pathological language processing. *Journal of Neurolinguistics, 16*, 43–58.
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*, 203–205.
- Kutas, M., & Hillyard, S. A. (1983). Event-related potentials to grammatical errors and semantic anomalies. *Memory and Cognition, 11*, 539–550.
- Näätänen, R. (1992). *Attention and brain function*. Hillsdale, NJ: Erlbaum.
- Näätänen, R. (2001). The perception of speech sounds by the human brain as reflected by the mismatch negativity (MMN) and its magnetic equivalent (MMNm). *Psychophysiology, 38*, 1–21.
- Näätänen, R., & Alho, K. (1997). Mismatch negativity—The measure for central sound representation accuracy. *Audiology & Neuro-otology, 2*, 341–353.
- Näätänen, R., Gaillard, A. W. K., & Mäntysalo, S. (1978). Early selective-attention effect on evoked potential reinterpreted. *Acta Psychologica, 42*, 313–329.
- Näätänen, R., Tervaniemi, M., Sussman, E., Paavilainen, P., & Winkler, I. (2001). “Primitive intelligence” in the auditory cortex. *Trends in Neurosciences, 24*, 283–288.
- Neville, H., Nicol, J. L., Barss, A., Forster, K. I., & Garrett, M. F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 3*, 151–165.
- Ni, W., Constable, R. T., Mencl, W. E., Pugh, K. R., Fulbright, R. K., Shaywitz, S. E., et al. (2000). An event-related neuroimaging study distinguishing form and content in sentence processing. *Journal of Cognitive Neuroscience, 12*, 120–133.
- Nordby, H., Hammerborg, D., Roth, W. T., & Hugdahl, K. (1994). ERPs for infrequent omissions and inclusions of stimulus elements. *Psychophysiology, 31*, 544–552.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*, 97–113.

- Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, *31*, 785–806.
- Osterhout, L., & Mobley, L. A. (1995). Event-related brain potentials elicited by failure to agree. *Journal of Memory and Language*, *34*, 739–773.
- Paavilainen, P., Simola, J., Jaramillo, M., Näätänen, R., & Winkler, I. (2001). Preattentive extraction of abstract feature conjunctions from auditory stimulation as reflected by the mismatch negativity (MMN). *Psychophysiology*, *38*, 359–365.
- Perani, D., Cappa, S. F., Schnur, T., Tettamanti, M., Collina, S., Rosa, M. M., et al. (1999). The neural correlates of verb and noun processing. A PET study. *Brain*, *122*, 2337–2344.
- Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.
- Pulvermüller, F. (2002). A brain perspective on language mechanisms: From discrete neuronal ensembles to serial order. *Progress in Neurobiology*, *67*, 85–111.
- Pulvermüller, F., Mohr, B., & Schleichert, H. (1999). Semantic or lexico-syntactic factors: What determines word-class specific activity in the human brain? *Neuroscience Letters*, *275*, 81–84.
- Pulvermüller, F., & Shtyrov, Y. (2003). Automatic processing of grammar in the human brain as revealed by the mismatch negativity. *Neuroimage*, *20*, 159–172.
- Sabri, M., & Campbell, K. B. (2000). Mismatch negativity to inclusions and omissions of stimulus features. *NeuroReport*, *11*, 1503–1507.
- Schneider, W., Dumais, S. T., & Shiffrin, R. M. (1984). Automatic and control processing and attention. In R. Parasuraman, & D. R. Davies (Eds.), *Varieties of attention* (pp. 1–27). New York: Academic Press.
- Schriefers, H., Friederici, A. D., & Rose, U. (1998). Context effects in visual word recognition: Lexical relatedness and syntactic context. *Memory & Cognition*, *26*, 1292–1303.
- Shapiro, K., & Caramazza, A. (2003). The representation of grammatical categories in the brain. *Trends in Cognitive Sciences*, *7*, 201–206.
- Shapiro, K. A., Pascual-Leone, A., Mottaghy, F. M., Gangitano, M., & Caramazza, A. (2001). Grammatical distinctions in the left frontal cortex. *Journal of Cognitive Neuroscience*, *13*, 731–720.
- Sharbrough, F. (1991). American Electroencephalographic Society Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *8*, 200–202.
- Shtyrov, Y., & Pulvermüller, F. (2002). Memory traces for inflectional affixes as shown by mismatch negativity. *European Journal of Neuroscience*, *15*, 1085–1091.
- Shtyrov, Y., Pulvermüller, F., Näätänen, R., & Ilmoniemi, R. J. (2003). Grammar processing outside the focus of attention: An MEG study. *Journal of Cognitive Neuroscience*, *15*, 1195–1206.
- Tervaniemi, M., Maury, S., & Näätänen, R. (1994). Neural representations of abstract stimulus features in the human brain as reflected in the mismatch negativity. *NeuroReport*, *5*, 844–846.
- Vos, S. H., Gunter, T. C., Kolk, H. H. J., & Mulder, G. (2001). Working memory constraints on syntactic processing: An electrophysiological investigation. *Psychophysiology*, *38*, 41–63.
- Wright, B., & Garrett, M. (1984). Lexical decision in sentences: Effects of syntactic structure. *Memory & Cognition*, *12*, 31–45.