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Gender Electrified: ERP Evidence on the Syntactic Nature of Gender Processing

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The central issue of this study concerns the claim that the processing of gender agreement in on-line sentence comprehension is a syntactic rather than a conceptual/semantic process. This claim was tested for the grammatical gender agreement in Dutch between the definite article and the noun. Subjects read sentences in which the definite article and the noun had the same gender and sentences in which the gender agreement was violated. While subjects read these sentences, their electrophysiological activity was recorded via electrodes placed on the scalp. Earlier research has shown that semantic and syntactic processing events manifest themselves in different event-related brain potential (ERP) effects. Semantic integration modulates the amplitude of the so-called N400. The P600/SPS is an ERP effect that is more sensitive to syntactic processes. The violation of grammatical gender agreement was found to result in a P600/SPS. For violations in sentence-final position, an additional increase of the N400 amplitude was observed. This N400 effect is interpreted as resulting from the consequence of a syntactic violation for the sentence-final wrap-up. The overall pattern of results supports the claim that the on-line processing of gender agreement information is not a content driven but a syntactic-form driven process.

Compared to devices such as tense and aspect, the linguistic status of gender is less clear. On the one hand, the relation between the particular gender of a noun and the properties of the noun referent often seem completely arbitrary and can vary from language to language. For instance, the word for house has masculine gender in Russian, is feminine in French, and neuter in Tamil (Corbett, 1991). On the other hand, Corbett (1991), among other linguists,

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has argued that in many cases the gender of a noun can be derived from other properties of the noun or the noun referent. This raises the issue whether the processing of grammatical gender is driven purely by syntactic form or is influenced by conceptual/semantic factors. At the same time, however, gender behaves as a syntactic phenomenon during the construction or interpretation of a phrasal configuration. That is, it is determined by the nature of the syntactic relation between nouns and other word classes (determiner, adjective, verb, etc.). Thus, whatever the diachronic roots of noun gender, establishing gender agreement between the noun and, for instance, an article or adjective during on-line processing is most often seen as a purely syntactic process. The present study aimed at collecting electrophysiological evidence for the claim that the processing of gender agreement in on-line sentence comprehension is a syntactic rather than a conceptual/semantic process.

Recent accounts of the human language system (Jackendoff, 1997, 1999; Levelt, 1999) assume a tripartite architecture, in which, next to processing levels for conceptual/semantic structures and orthographic/phonological structures, there is a separate level of syntactic processing. In Levelt's terminology (1989), this is referred to as the lemma level. The lemma level specifies the syntactic properties of words, including grammatical gender. If gender agreement is established at this level, its effects should pattern with other classes of syntactic processing phenomena. However, if establishing gender agreement is influenced by conceptual information, we should be able to (also) find a correlation with other types of conceptual/semantic processing.

The approach we took to investigate this question was to exploit types of electrophysiological brain activity that have been shown to honor the distinction between the processing of syntactic and semantic information in language comprehension (cf. Hagoort, Brown, & Osterhout, 1999). The central question of this study was whether neurophysiological evidence supports the claim that establishing gender agreement is a purely syntactic process.

To investigate this issue, we exploited the characteristics of the gender system in Dutch. Dutch nouns have either one of two grammatical genders: common gender and neuter gender (Van Berkum, 1996). When produced with a definite article, a singular noun phrase is gender marked by the article of the noun. The definite article *de* is used for nouns of common gender, whereas the definite article *het* is used for nouns of neuter gender.

Event-related brain potentials (ERPs) were recorded while participants read sentences containing noun phrases with either a correct agreement between the definite article and the noun or sentences in which there was a gender mismatch between article and noun, e.g., when a neuter article is combined with a noun of common gender.

ERPs are electrical changes recorded from the brain and induced by an external stimulus or internal processing event. ERPs are usually recorded from electrodes placed on the scalp. One of the interesting aspects of the ERP signal is that, in principle, qualitatively different processing events can show up as latency or amplitude modulations of qualitatively distinct ERP components. An important example in this context is the distinction between semantic and syntactic ERP effects in comprehension. The processing of semantic information is found to influence the amplitude of a negative-going ERP component between roughly 250 and 600 ms, and with a maximal amplitude at about 400 ms (Kutas & Hillyard, 1980). This amplitude modulation is referred to as the N400 effect. Usually the N400 effect is bigger over electrode sites on the back of the head than over the front of the head. The N400 effect can be observed to words in the context of another word, of a sentence, or of a larger discourse. The easier the match between the lexical semantics of a particular content word and the semantic specification of the context, the more reduced the amplitude of the N400. The antecedent conditions of the N400 effect suggest that it is especially sensitive to post-lexical semantic integration processes (Brown & Hagoort, 1993, 1999).

Next to the semantic N400 effect, two syntax-related ERP effects have been reported in recent years. One is a negative shift in the ERP waveform within the same latency range as the N400, but with a clearly more frontal distribution. The frontal negativities go under different names, but are most often referred to as the left anterior negativity (LAN). The second syntax-related ERP is a positive polarity shift that starts at about 500 ms and can continue for some 500 ms. This effect is referred to as the P600/SPS (syntactic positive shift). The frontal negativities are observed to morphosyntactic violations (Münte, Heinze, & Mangun, 1993; Münte & Heinze, 1994) and to violations of the word category that the phrase structure requires at each position during incremental sentence processing (Friederici, Hahne, & Mecklinger, 1996). The P600/SPS is seen to a larger series of syntactic violations, including phrase structure violations, subcategorization violations, violations in the agreement of number and case (cf. Hagoort *et al.*, 1999, for a review), and also to violations of syntactic preferences in syntactically ambiguous sentence structures (Van Berkum, Brown, & Hagoort, 1999; Osterhout, Holcomb, & Swinney, 1994).

Although the existence of language-related ERP effects does not allow the inference that they are language-specific, nevertheless, within the domain of language processing, different ERP effects are triggered by operations at different levels of the tripartite architecture of human language processing. As such these ERP effects support the claim of the domain specificity of, for example, semantic and syntactic processing. This characteristic of language-related ERP effects will be exploited in this study on the nature of gender

processing. More specifically, if gender agreement is a purely syntactic phenomenon, we expect experimental manipulation of gender agreement to show up as a LAN or P600/SPS effect.

A first study on the ERP effects of gender violations was done by Osterhout and Mobley (1995). These authors presented their subjects with sentences in which the reflexive pronoun either agreed or disagreed in gender with the antecedent (e.g., "The woman congratulated herself/*himself on the promotion."). This violation resulted in a P600/SPS, but not a LAN effect. However, in a recent study with German materials, Gunter, Friederici, and Schriefers (unpublished manuscript) obtained both a P600/SPS and a LAN to a violation of gender agreement. In the present study we manipulated the agreement between the grammatical gender of the definite article and the noun in Dutch. Since gender agreement between article and noun in Dutch is neither marked as a bound morpheme on the noun, nor impacts the phrase structure level, a LAN is not expected in relation to the processing of gender agreement (cf. Friederici *et al.,* 1996; Münte *et al.,* 1993; Münte & Heinze, 1994). In our case, therefore, we expect our experimental manipulation of gender agreement to show up as a P600/SPS effect.

METHOD

Materials

The materials consisted of 515 items, including practice, starter, and filler items. For the purposes of this study the relevant materials consisted of 320 sentence pairs. Sentences had a mean length of 7.7 words (*SD:* 1.2 words). All sentences were simple active sentences. Each sentence pair contained one sentence with a violation of the gender agreement between the definite article and the noun, and its counterpart with a correct agreement. Half of the critical sentences had a gender violation in the first noun phrase of the sentence, the other half in the sentence-final noun phrase. The condition with a violation in sentence-final position was added to compare our results with syntactic violation results of other ERP studies. In many ERP studies violation effects are elicited in sentence-final position. For both sentence-medial and sentence-final violations, the violation of the gender agreement became clear at the noun. Here is an example of sentence pairs with sentence-medial and sentence-final violations (the critical nouns are underlined):

(1) De kapotte *paraplu* staat in de garage.
*Het kapotte *paraplu* staat in de garage.

(The_{com}/The_{neut} broken $umbrella_{com}$ is in the garage.)

(2) Cindy sliep slecht vanwege de griezelige *droom.*
*Cindy sliep slecht vanwege het griezelige *droom.*

(Cindy slept badly due to the_{com}/the_{neut} scary $dream_{com}$.)

The materials were constructed in such a way that 50% of the sentences contained a gender violation. Violations of gender agreement could occur after both a common gender and a neuter gender article. In this way, violations of gender agreement could not be predicted on the basis of probability or sentence context. The materials were distributed among different versions of the experiment such that no subjects saw more than one version of a sentence pair, but across subjects the critical items were distributed equally over both conditions.

Participants

Twenty-four young subjects from the MPI subject pool participated in this study. All subjects had normal or corrected-to-normal vision and were right-handed. Subjects were paid for participation.

Procedure

Sentences were presented word by word in the center of a high-resolution computer screen. Each word was presented for 300 ms, followed by a blank screen for another 300 ms, after which the next word of the sentence appeared. The final word of the sentence was presented together with a period sign. After a variable delay (minimally 1 s) from sentence offset, a row of asterisks appeared on the screen, signaling to the subjects that they had to push one of two response buttons indicating whether the sentence was acceptable or not.

EEG Recording and Analysis

ERPs were recorded from 13 electrode sites across the scalp (see Fig. 1) using standard recording procedures and with a time constant of 8 s. The recording sites included three sites over the midline, five sites over the left hemisphere, and five sites over the right hemisphere. ERPs were quantified by mean amplitude measures in 300- to 500-ms and 500- to 700-ms time windows following the onset of the critical noun. Mean amplitudes were computed for each subject, relative to a baseline of 150 ms preceding the critical noun. The resulting mean amplitude values were entered into a repeated measures analysis of variance with gender (2 levels), position (2 levels) and electrode-site (13 levels) as completely crossed factors.

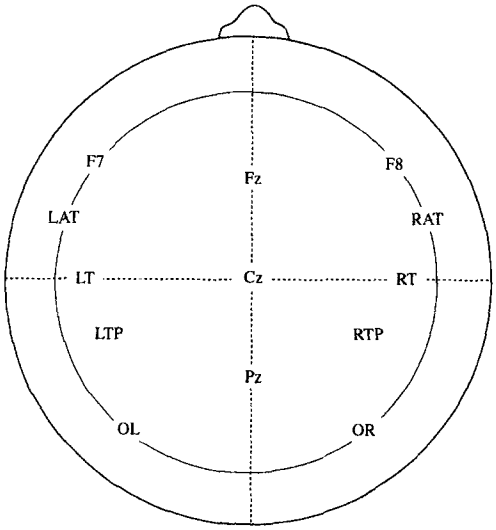

Fig. 1. A flat projection of the electrode positions from which ERPs were recorded. The projection is from front to back, with the nose in front of (at top). ERPs were recorded from standard midline positions (Fz, Cz, Pz) and standard frontal sites (F7, F8). In addition, ERPs were recorded from left and right anterior temporal sites (LAT, RAT), left and right temporal (LT, RT), left and right temporoparietal (LTP, RTP), and left and right occipital sites (OL, OR).

RESULTS

According to the results of the acceptability judgement task, subjects found 95% of the correct sentences acceptable, and 97% of the sentences with a violation of gender agreement unacceptable. This clearly demonstrates the sensitivity of subjects to the gender marking of the noun phrases.

For the sentence-medial gender violation, Fig. 2 shows an overlay of the ERP waveforms at a central midline electrode site (Cz) for the noun in the gender violation and the control condition. Different ERP components are clearly visible in the ERP waveform for both conditions. A N1 component at around 120 ms is followed by a P2 component at about 200 ms. These ERP components are followed by the N400 with a maximal amplitude at roughly 400 ms. Since the word that follows the noun is presented at 600 ms, at around 720 one can see the N1 elicited by this next word and the following P2 at about 800 ms.

As can be seen, the most salient difference between the ERPs for the two conditions is a substantial positive deflection of the waveform for the gender violation. This positive deflection starts at about 500 ms and carries

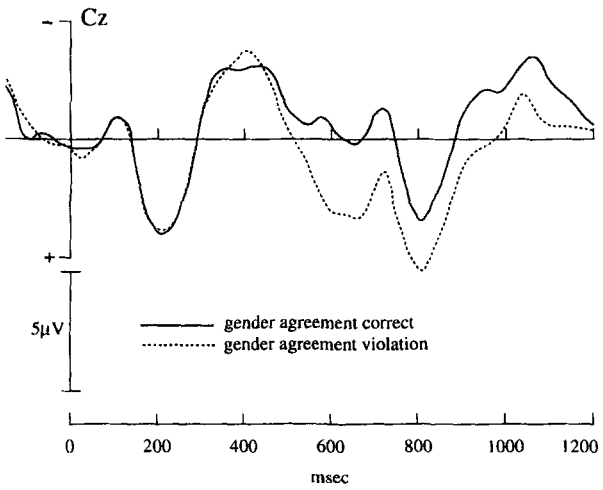

Fig. 2. ERP waveforms at the central midline electrode (Cz) for the correct gender agreement and the gender agreement violation in sentence-medial position. The critical noun is presented at time zero. At 600 ms the next word appeared on the screen. Negativity is plotted upwards in this and all other figures.

over into the processing epoch of the following word. Inspection of the other electrode sites (see Fig. 3) shows that this positive shift is largest over the back of the head, with an equal distribution over both hemispheres. On the basis of the polarity, the latency, and the scalp distribution of this ERP effect, it can be unambiguously characterized as a P600/SPS.

Figure 3 shows all electrode sites for the sentence-medial violation, including Cz that was shown as the representative site in Fig. 2. This figure suggests that in addition to the P600/SPS, a slightly increased negativity might be present over the left fronto-temporal electrode sites (i.e., F7, LAT, LT) within the 300- to 500-ms range. However, an ANOVA over the mean amplitudes within this latency range for these three electrode sites and separate ANOVAs for each of these individual electrode sites showed that this difference was not significant (all p s = .20 or larger).

Figure 4 shows the sentence-final gender violation effect. Again a P600/SPS is visible, with a similar distribution across the scalp as for the sentence-internal violation. However, in sentence-final position the P600/SPS is preceded by a negative shift within the 300- to 500-ms latency range. Over the lateral sites, this negative shift increases from frontal to parietal sites (see Fig. 5). Over the midline sites the effect is largest over the central electrode site (Cz). As can be seen in Fig. 5, the P600/SPS is only present over posterior sites including Cz.

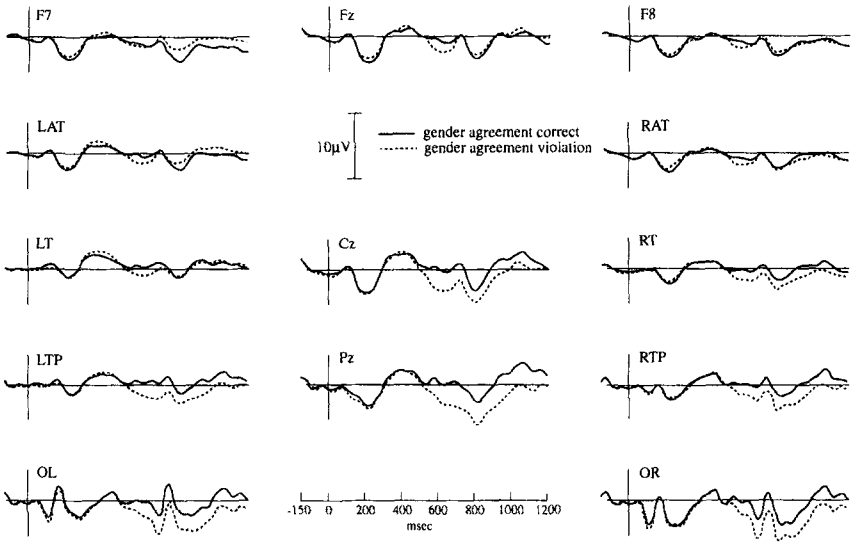

Fig. 3. ERP waveforms at all 13 electrode sites (see Fig. 1) for the correct gender agreement and the gender agreement violation in sentence-medial position. The critical noun is presented at time zero. At 600 ms the next word appeared on the screen.

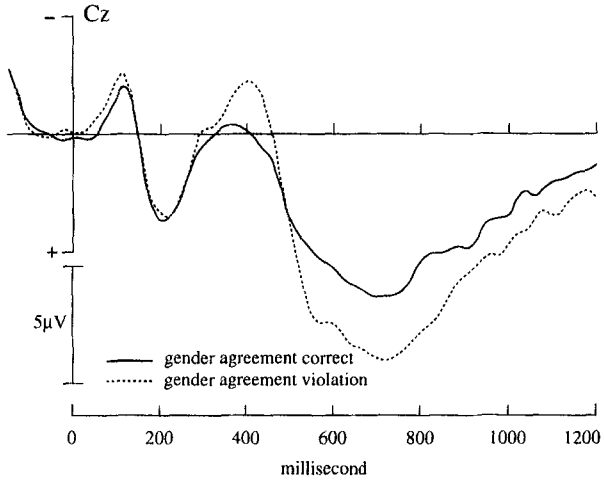

Fig. 4. ERP waveforms at the central midline electrode (Cz) for the correct gender agreement and the gender agreement violation in sentence-final position. The critical noun is presented at time zero.

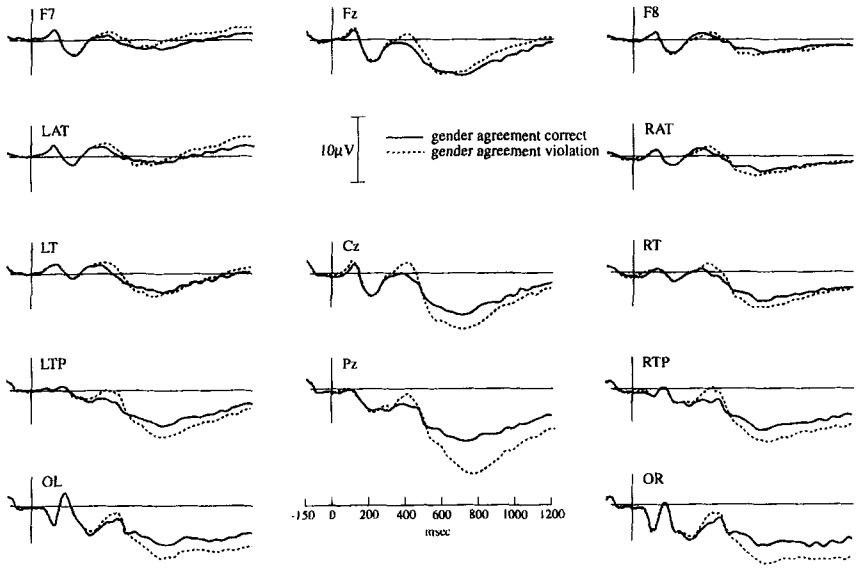

Fig. 5. ERP waveforms at all 13 electrode sites (see Fig. 1) for the correct gender agreement and the gender agreement violation in sentence-final position.

The overall ANOVAs supported the impression from Figs. 2–5. For the 300- to 500-ms latency range the gender violation resulted in a significant main effect [$F(1, 23) = 4.77$, $MSE = 30.5$, $p = .039$]. However, this effect was qualified by a marginally significant gender × position interaction [$F(1, 23) = 3.33$, $MSE = 25.8$, $p = .081$]. Separate analyses for the sentence-medial and sentence-final violations resulted in a significant effect for the sentence-final position [$F(1, 23) = 7.77$, $MSE = 29.3$, $p = .011$], but not for the sentence-medial position ($F < 1$).

The ANOVA on the P600/SPS latency range (500–700 ms) resulted in a highly significant effect of the gender violation [$F(1, 23) = 40.57$, $MSE = 21.5$, $p < .0001$). This effect was not different in sentence-internal and sentence-final position, as indicated by the absence of a position × gender interaction ($F < 1$).[3]

[3] Since in sentence-final position the P600/SPS is preceded by an increased negativity to gender agreement violation, we also analyzed the data after renormalization in the 300- to 500-ms latency window. In this way we tried to compensate for the possible overlap between negative and positive shifts. The ANOVA on the renormalized data showed the same results as the analyses on the data with a prestimulus normalization.

DISCUSSION

The results of this study are very clear-cut. A violation of the gender agreement between the article and the noun in Dutch noun phrases resulted in a classical P600/SPS (cf. Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992; Osterhout, McLaughlin, & Bersick, 1997). This effect was independent of the position of the agreement violation within the sentence. Although, intuitively, the semantic interpretation of the sentences was not particularly affected by the gender mismatch between the definite article and the noun, both the acceptability judgements and the brain responses showed a significant sensitivity of the language processing system to violations of gender agreement.

In addition to the P600/SPS, an increased negativity was observed in a latency range preceding the P600/SPS. However, this negativity only arose to violations in sentence-final position. Over lateral sites the negativity had the classical distribution of the N400, increasing in amplitude from frontal to posterior sites, and slightly larger over right than left posterior sites. Over the three midline sites (Fz, Cz, Pz) the effect was largest over Cz, whereas classically the visual N400 is largest over Pz. However, inspection of the waveforms suggests that the N400 amplitude at the Pz site is reduced due to the overlap of the following P600/SPS, which has a posterior maximum. Thus, although it cannot be completely excluded that the observed negativity is similar to syntax-related negativities with a frontocentral distribution that have been reported in relation to morphosyntactic incongruities (Münte, Matzke, & Johannes, 1997), it is much more likely that the negativity we obtained is a classical N400 effect.

In contrast to a recent study in German (Gunter et al., unpublished manuscript) the gender agreement violation in Dutch did not elicit a LAN effect. It is beyond the scope of this paper to speculate about the reason why these authors found a LAN effect. Given what is known about the usual antecedent conditions for LAN effects (e.g., morphosyntactic and word category violations), a LAN effect was not expected in our study. The reason is that in our study the article with the wrong gender marking did not induce a difference in word category expectation (i.e., a noun is expected following both the *de* and *het* articles). Nor is there in Dutch a concomitant difference in the morphosyntactic make-up of the noun by an overt gender-marking on the noun.

In summary, violations of gender agreement resulted in a P600/SPS and an additional N400 effect when the violation was in sentence-final position. We will now turn to the theoretical implications of these results.

Earlier ERP studies on language processing (see for reviews Osterhout *et al.,* 1997; Hagoort *et al.,* 1999) have found that qualitatively different

ERP effects are observed to distinct levels of processing within the tripartite architecture of the human language system. The P600/SPS is shown to be especially sensitive to aspects of syntactic processing. This ERP effect is observed to a large class of syntactic anomalies, including verb tense anomalies ("The cats won't *eating* the food that Mary leaves them."; Osterhout *et al., 1997*) and violations of the required agreement in number between subject and verb ("The men *throws* the ball."; Hagoort *et al.,* 1993; Hagoort & Brown, 1994), and between a reflexive and its antecedent ("The hungry guests helped *himself* to the meal."; Osterhout & Mobley, 1995). The results of the current study indicate that establishing gender agreement between article and noun patterns with the processing of tense, number, and other agreement phenomena, in that its processing characteristics are syntactic in nature. Thus, whatever the diachronic source of the noun's gender, the processing of its lexically frozen gender features, and more particularly the unification of the gender feature value of the noun with that of the definite article during the on-line processing of noun phrases, seems to be a syntactic process. Other results indicate that what holds for the unification of noun gender features and the gender features of the article, also applies to other gender agreement phenomena. Osterhout and Mobley (1995) found a P600/SPS to a gender mismatch between a reflexive and its antecedent, as in "The successful woman congratulated *himself* on the promotion." Van Berkum, Brown, and Hagoort (this issue) report a P600/SPS to a gender mismatch between a noun and the relative pronoun that it controls in Dutch. Therefore, the conclusion seems justified that in on-line language comprehension establishing gender agreement between the noun and the agreement target (e.g., article, adjective, reflexive or relative pronoun) occurs at the syntactic level within the tripartite architecture of the human language system.

How does this conclusion fare in the context of the observed N400 effect to sentence-final violations? For various reasons, presenting the critical words in sentence-final position can impact the overall morphology of the ERP waveform and thereby complicate the comparison with results obtained to words in other than sentence-final positions. It is well known in the reading-time literature that apart from local effects, sentence-final words are often strong attractors of global processing factors related to sentence wrap-up, decision, and response requirements (e.g., Mitchell & Green, 1978; Schriefers, Friederici, & Kuhn, 1995). For example, in sentences that subjects judge as unacceptable, final words elicit an enhanced N400-like effect, regardless of whether the unacceptability is semantic or syntactic in nature (Hagoort *et al.,* 1993; Osterhout & Holcomb, 1992, 1993). The ERP effects of the local violation and the more global ERP effects of sentence processing thus tend to overlap most strongly in sentence-final position, thereby particularly affecting the resulting ERP wave-

forms for the local effect in this position (cf. Hagoort *et al.,* 1999). The additional N400 effect in sentence-final position that we observed in this study is therefore presumably related to the consequences of the gender violation for the overall integration of the sentential information into one coherent message.

One aspect of the results seems at odds with this account. This is that the N400 effect precedes the P600/SPS in time, which raises the following issue: What does the latency of the P600/SPS imply about the time course of syntactic versus semantic integration processes? The fact that the syntactic violation had its impact already on the N400 proves that the relevant syntactic information was available before it manifested itself in the P600/SPS. Earlier syntax-related ERP effects in the literature (e.g., Friederici *et al.,* 1996) support this claim. The relative onset of N400 effects and the P600/SPS can therefore not be taken as a direct estimate of the relative time courses of parsing operations and semantic integration processes. We offer two potential explanations for the onset differences between the N400 effect and the P600/SPS.

One explanation relates to the general nature of language-relevant ERPs. Currently, there is no single language-relevant ERP for which the claim can be made that it is language-specific. That is, we do not know whether the different language processing events that we are interested in are directly or only indirectly reflected in the ERP effects. This complication has its parallel in PET and fMRI, where it is often unknown whether an area of increased hemodynamic response is the source of the cognitive operation or the site where it has its effect. With respect to ERPs, with their millisecond time-course resolution, we face the problem that if the scalp-recorded potential is only indirectly related to the cognitive operation under investigation, the time course of the ERP can be displaced in time relative to the time course of the cognitive operation by an unknown amount. This implies that the latency of an ERP effect reflects the upper bound on the estimation of the time course of a cognitive operation (Rugg & Coles, 1995).[4] The onset of the cognitive operation might have preceded the moment where it started to manifest itself in its ERP index. Moreover this delay is not necessarily identical for the different language-relevant ERP effects. This, no doubt, complicates deriving straightforward conclusions from the relative moments in time of qualitatively distinct ERP effects. It could, in part, explain the delay of the P600/SPS relative to the onset of the N400 effect.

[4] What we do not know for language-relevant ERP effects, we do know for the lexical decision task, naming, and other speeded response measures. All these measures are indirect, since they require at least transmission of information from brain areas relevant for a cognitive operation to the motor cortex in order to result in the actual execution of the speeded response. This obvious fact is often ignored in on-line RT studies of language processing.

However, for all we know about the speed of information transmission in the brain, most likely the actual onset difference between N400 effect and P600/SPS can only be partly explained by differences in the delay between a cognitive process and its ERP manifestation. Functional differences related to the cognitive architecture of language comprehension might also be at stake. One such difference is that semantic integration is a very immediate process (Marslen-Wilson, 1989). The processing costs involved in integrating word meaning into the ongoing sentence interpretation can vary, resulting in modulations of the N400 amplitude. The P600/SPS, however, might be related to the outcome of parsing operations rather than directly reflecting these operations themselves. That is, if a parsing operation fails because unification cannot take place on the basis of the available feature specifications, a P600/SPS is elicited. If this functional interpretation is correct, it implies that the P600/SPS is not directly related to the unification process itself, but to its failure, which follows this process in the case of feature mismatch. By this account, the processing consequences for a more complicated unification process might already be felt in the semantic integration operations before the unification process comes to a halt.

Whatever the ultimate explanation for the relative time course of the N400 effect and the P600/SPS, the qualitative distinction between these two effects demonstrates the processing and/or representational uniqueness of the underlying components of the neurocognitive machinery for language. To the extent that within the domain of language processing the P600/SPS qualifies as an electrophysiological manifestation of the processing of syntactic information, the findings of this study support the claim that the online processing of gender agreement information is not a content driven but a syntactic-form driven process.

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