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Semantics prevalence over syntax during sentence processing: A brain potential study of noun–adjective agreement in Spanish

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ABSTRACT

A review of the literature about the interplay of syntax and semantics, using event-related brain potentials (ERPs), revealed that the results are highly heterogeneous, owing to several possible variables. An experiment was conducted with Spanish sentences that factorially combined syntactic and semantic violations in the same sentence-intermediate adjective and controlled for working memory demands, variables that in previous studies have rarely been taken into consideration. Violations consisted in noun–adjective number or gender disagreements (syntactic violation), noun–adjective semantic incompatibility (semantic violation), or both (combined violation). The N400 to semantic violations was unaffected by additional syntactic violations. The P600/SPS component, considered to reflect syntactic processes, was elicited by both single syntactic and semantic violations but seemed to be diminished in combined violations relative to single syntactic violations. These results suggest that under the conditions of the present experiment semantic information may have a prevailing role over syntactic information.

1. Introduction

Most current models of language processing agree that different types of constraints have to be considered during sentence comprehension (Jackendoff, 2002). Two of these constraints will be in the focus of this article: conceptual/semantic and syntactic information. It is a matter of considerable debate in psycholinguistics exactly how these constraints are implemented in the sentence processing machinery. From one point of view, separable, independent, and at least partly sequential processes construct distinct syntactic and semantic representations of a sentence (Berwick and Weinberg, 1984; Ferreira and Clifton, 1986). The opposed view is that syntactic and semantic constraints directly and simultaneously interact with each other at the message-level representation of the input (Johnson-Laird, 1983; Marslen-Wilson and Tyler, 1987; McClelland et al., 1989). In between these two extremes – fully independent vs. fully interactive models – there are other proposals. One of these suggests that initially syntactic analysis is autonomous and independent of

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semantic variables but is affected by them at later stages; in contrast, semantic integration can be influenced by syntactic analysis from the very beginning of processing (Frazier, 1987). Yet, another proposal claims that semantic information immediately and directly guides syntactic analysis of the utterance (Trueswell et al., 1994).

These and several other diverging views can be tested by using event-related brain potentials (ERPs) elicited during sentence comprehension. ERPs offer millisecond temporal resolution, permitting online measurements of brain activity as language processing unfolds over time. Different reliable ERP components have been shown to honor the distinction between the processing of syntactic and semantic information during sentence processing. The extent and type of interaction of these various brain responses can be taken as evidence for the kind of interplay occurring between syntactic and semantic analyses during sentence comprehension.

When the manipulated variable is semantic, it mainly affects the so-called N400 component (Kutas and Hillyard, 1980). Typically, the N400 is observed to words in a context (usually a sentence), increasing in amplitude with the difficulty of semantically integrating these words into their context (Chwilla et al., 1995). The N400 effect is a negative-going ERP deflection between roughly 250 and 550 ms that is usually larger over central and posterior than over frontal electrode sites (Kutas and Besson, 1999).

When the manipulated variable belongs to the syntactic domain, the main findings are anterior negativities and posterior positivities. Anterior negativities have been typically labeled as LAN (left anterior negativity), resembling the N400 in latency, or ELAN (early LAN), appearing as early as between 100 and 200 ms. Word category violations are the anomalies most frequently associated with ELAN (e.g., Friederici and Mecklinger, 1996), whereas other grammatical anomalies, including morphosyntactic violations, usually evoke a LAN (e.g., Coulson et al., 1998). The second syntax-related component, appearing later and labeled P600 or syntactic positive shift (SPS), has been found for syntactic violations (e.g., Osterhout and Holcomb, 1992) but also for structurally ambiguous or garden path sentences (Frisch et al., 2002). The P600/SPS has been suggested to indicate syntactic processing costs of revisions and reanalyses required by structural mismatches (Münte et al., 1998). Recent reviews on ERP components related to semantic and syntactic processes are provided by Federmeier et al. (2003), Friederici (2004), and Kutas et al. (in press).

In order to study how the semantic and syntactic constraints are implemented during sentence processing and whether they are independent or interactive, factorial designs are frequently used in which semantic and syntactic violations are presented both in isolation and in combination. Observing whether and how N400, LAN (or ELAN), or the P600/SPS components are modified in combined violations relative to single violations allows for conclusions regarding the interplay of syntax and semantics during sentence comprehension. However, although a number of ERP studies have been conducted with this type of design, the results about the kind of interplay of semantic and syntactic information during sentence processing are strikingly heterogeneous. One aim of the present paper is to review existing studies on the interplay of syntax and semantics, pointing out the heterogeneity of findings and suggesting possible reasons for this state of affairs. The second aim is to report an experiment that takes into consideration some of the possibly critical issues.

1.1. *Review of previous findings on syntax–semantics interplay*

Table 1 presents an overview of studies that have used factorial designs in order to study the interplay of semantics and syntax. In all these studies, it was of interest how N400 and syntax-related ERP components to words combining semantic and syntactic violations (henceforth combined violations) compares to these components when obtained for each single violation type. In a first group, violation effects summate in an approximately linear manner in LAN and N400 but P600/SPS appears somewhat reduced (Gunter et al., 1997, 2000). According to these results, semantic and syntactic processes seem to be independent in a first processing phase (reflected in LAN and N400). However, during a later phase, syntactic processing, as reflected in the P600/SPS, might be attenuated by semantic information.

In a second group of studies, the N400 effect of single semantic violations disappeared when combined with syntactic violations. In contrast, LAN or ELAN and P600/SPS of single syntactic violations were unaffected by additional semantic violations (Friederici et al., 1999, 2004; Hahne and Friederici, 2002; Ye et al., 2006). Thus, according to these findings, syntactic processing seems to be unaffected by and prevailing over semantic processes.

However, the non-homogeneity of ERP studies on the interplay of syntax and semantics is not confined to these two extremes. Osterhout and Nicol (1999) concluded that both types of processes are to a large extent independent, despite the fact that in their study both N400 and P600 (LAN or ELAN were not elicited) appeared slightly reduced in combined relative to single violations. Ainsworth-Darnell et al. (1998) drew similar conclusions from similar results, although in their case N400 and P600/SPS reductions in combined violations were not significant (possibly because they did not analyze the Pz electrode, where these changes appeared most pronounced).

Palolahti et al. (2005) have recently reported that LAN and N400 summate but do so in underadditive fashion, that is, ERPs in the combined violation condition were smaller in amplitude than the arithmetic sum of LAN and N400 in single violations. In contrast, the P600/SPS remained unaffected in combined violations. The authors concluded that an early interaction of syntax and semantics is followed by independence during later processing stages.

Hagoort (2003) found the N400 to single semantic violations to be increased in amplitude by an additional syntactic violation, whereas the P600/SPS to single syntactic violations was unaffected by an additional semantic violation. Therefore, Hagoort concluded that syntax plays a prevailing role over semantics during sentence processing. It must be commented, however, that in order to analyze the P600/SPS, Hagoort (2003) recalculated the ERP baseline with respect to a window centered on the N400 latency. With a conventional prestimulus baseline, the P600/SPS was significantly reduced by semantic information.

Table 1 – ERP studies using a factorial design to determine the syntax–semantics interplay during sentence processing

	Variables affecting results							Results			
	Pos.	Cat.	Type	WM and integration costs of the violations	Lang.	Mod.	Task Dem.	Sem. Viol.	Synt. Viol.	Comb. Viol.[a]	P600, new baseline[b]
Ainsworth-Darnell et al., 1998	Inter	Noun	W-C[c]	Sem > Syn. Sem.: relative to previous verb; Syn.: relative to preposition following auxiliary verb	English	Visual	Comp.	N400, small P600[d]	P600	↓N400, ↓P600[e]	
Friederici et al., 1999	Inter	Verb (past participle)	W-C	Sem > Syn. Sem.: relative to noun preceding auxiliary verb; Syn.: relative to preposition following auxiliary verb	German	Visual	Probe verif.	N400, late Negativity	ELAN, P600	ELAN, ↓P600	
Friederici et al., 2004	Inter	Verb (past participle)	W-C	Sem > Syn. Sem.: relative to noun preceding auxiliary verb; Syn.: relative to preposition following auxiliary verb	German	Audit.	Probe verif.	N400	LAN, P600	LAN, ↑P600	
Gunter et al., 1997	Final	Verb (past participle)	Morph.	Sem < Syn. Sem.: relative to noun preceding auxiliary verb; Syn.: relative to auxiliary verb	Dutch	Visual	Comp.	N400, small P600	ELAN[f], LAN, P600	N400 + ELAN, LAN, ↓P600	
Gunter et al., 2000	Inter	Noun	Morph.	Sem > Syn. Sem.: relative to sentence context; Syn.: relative to immediately preceding determinant	German	Visual	Probe verif.	N400, late Negativity	LAN, P600	N400 + LAN, ↓P600	
Hagoort, 2003	Inter[g]	Noun	Morph.	Sem < Syn. Sem.: relative to immediately preceding adjective; Syn.: relative to article preceding that adjective	Dutch	Visual	Accept. judge.	N400	P600	↑N400, ↓P600	Comb = Syn
Hahne and Friederici, 2002	Final	Verb (past participle)	W-C	Sem > Syn. Sem.: relative to noun preceding auxiliary verb; Syn.: relative to preposition following auxiliary verb	German	Audit.	Accept. judge.	N400	ELAN, P600	ELAN, P600	
Osterhout and Nicol, 1999	Inter	Verb (infinitive)	Morph.	Sem > Syn. Sem.: relative to noun preceding future tense marker; Syn.: relative to future tense marker	English	Visual	Accept. judge.	N400	P600	↓N400, ↓P600	
Palolahti et al., 2005	Inter	Verb	Morph.	Sem = Syn. Both relative to immediately preceding noun	Finnish	Visual	Accept. judge.	N400	LAN, P600	N400 + LAN, ↓P600[h]	
Wicha et al., 2004	Inter	Noun	Morph.	Sem > Syn. Sem.: relative to sentence context; Syn.: relative to immediately preceding determinant	Spanish	Visual	Comp.	N400, small P600	P600	↑N400[i], ↓P600	Comb > Sem, Sem > Syn
Ye et al., 2006	Final	Verb	W-C	Sem > Syn. Sem.: relative to sentence context; Syn.: relative to immediately preceding particle	Chinese	Audit.	Accept. judge.	N400	ELAN, broad Neg.[j], long Ant. Neg.	ELAN, ↑broad Neg., long Ant. Neg.	

Finally, Wicha et al. (2004) reported that combined violations increased the N400 at frontal electrodes and decreased the P600/SPS, with single semantic violations eliciting a small P600/SPS in addition to the N400. This finding suggests some type of a continuous bi-directional interaction between syntax and semantics, which however was not found when replacing the critical word by a picture (Wicha et al., 2003a,b).

In summary, the presence and kind of interaction of semantics and syntax in ERP components are highly inconsistent across studies. Several authors claim to find evidence for an influence of semantic information on syntax but not of syntax on semantics. The reverse pattern has been found in other studies. A bi-directional influence of syntax and semantics has also been claimed, as well as independence between both processes. Finally, the interaction of syntax and semantics may also differ between early and late processing, but it is not clear to which of these phases one or the other type of interplay should be assigned.

1.2. *Possible causes of heterogeneity*

Hagoort (2003) recognized the problem of heterogeneous ERP results regarding the interplay between syntax and semantics and discussed two possible factors for this situation. One factor might be the use of different words eliciting semantic and syntactic violations in most relevant ERP studies. That is, semantic violations were caused by substituting a correct word at the critical position by a different word, whereas syntactic violations consisted in modifying the syntactic properties of the correct word while leaving the word as such in its place. However, if relevant variables such as familiarity or word length are controlled, as has been the case in most studies, any noticeable ERP difference related to the use of different words should disappear, particularly in relation to the N400 and P600/SPS components. A second possible problem raised by Hagoort (2003) is that in several ERP studies violations occurred in sentence-final positions. Sentence endings may have global effects on ERPs due to, for example, sentence "wrap-up" and response or decision processes that may overlap with the local effects on the ERPs due to the lexical element embodying the experimentally posed processing problem (Hagoort, 2003; Osterhout and Nicol, 1999). Therefore, Hagoort (2003) suggested that sentence-internal rather than sentence-final effects should be preferred. This proposal points out a limitation of the ERP technique for studying the syntax–semantic interplay at sentence-final positions.

However, apart from the factors suggested by Hagoort (2003), possibly causing heterogeneous effects, several others should also be considered as well. One of these might be the type (i.e., category) of the violating word. As pointed out by Townsend and Bever (2001), the syntax–semantics interaction is different for verbs than for other words since semantic properties of the verb determine probable thematic roles and, therefore, influence initial meaning/form hypotheses about the sentence (see also Dowty, 1988; Kutas and King, 1996). Previous ERP studies on syntax–semantics interplay did not explicitly take into account this variable, and violations occurred either in nouns or verbs. Interestingly, no other type of word has been studied (see Table 1).

In reviewing the ERP literature, one may also note another possible source of differences between studies, namely using either word category or morphosyntactic information for eliciting syntactic violations. Interestingly, in the three studies where the N400 disappeared in combined violations

Notes to Table 1:
Accept. judge.: acceptability judgment; subjects have to judge overall acceptability of each sentence.
Cat.: category of the violating word.
Comp.: comprehension task; subjects instructed to comprehend the sentences.
Lang.: language used in the study.
Mod.: modality of stimulus presentation.
Pos.: violation position in sentence (Inter.: intermediate position).
Probe verif.: probe verification task; after each sentence, subjects have to judge whether a probe word appeared in the sentence.
Sem < Syn: working memory and integration costs were higher for syntactic violations (referred to a word more distant than that for semantic violations).
Sem = Syn: semantic and syntactic violations equated in working memory and integration costs.
Sem > Syn: working memory and integration costs were higher for semantic violations (referred to a word more distant than that for syntactic violations).
Task Dem.: task demands.
Type: type of syntactic violation (Morph.: morphosyntactic violation; W-C: word category violation).
↑: amplitude increase relative to single violation.
↓: amplitude decrease relative to single violation.
[a] Relative to single violations.
[b] New baseline relative to N400 window.
[c] In strict sense, some authors would not consider this a word category violation, as an NP appears either.
[d] P600 non-significant, but remarkable at Pz electrode (not analyzed). A non-standard prestimulus baseline was used in this study.
[e] These changes were noticeable at Pz electrode (not analyzed). The only analyzed electrode was Cz, where effects were not significant.
[f] The interpretation of this negativity as syntax-related or as reflecting some type of visual template mismatch remained an open question in this study.
[g] Final position was also analyzed but overlooked from main conclusions.
[h] N400 and LAN summated non-additively. P600 reduction was not significant, but could be observed.
[i] N400 increase occurred at frontal electrodes.
[j] Broad negativity, attributed to others than the manipulated variables (namely, to "wrap-up" effects for sentence-final positions).

(Friederici et al., 1999, 2004; Hahne and Friederici, 2002), the syntactic violation concerned the word category. In contrast, a disappearance of the N400 in combined violations has never been reported when morphosyntax was involved (see Table 1).

In addition, there might be at least one other relevant factor. With the only exception of Palolahti et al. (2005), in all reported ERP experiments, the violations compared, even if occurring in the same word, differed in the point within the sentence relative to which they constitute a violation. Thus, whereas one violation (semantic or syntactic) occurs relative to the immediately preceding word, the other violation may occur relative to an element or elements appearing at least two words further back in the sentence. For instance, in the Hagoort (2003) study, syntactic violations in Dutch were of the type "Het kapotte paraplu…" ("The$_{neut}$ broken umbrella$_{com}$…"), where a violation is a gender disagreement between the first determinant and the noun. In contrast, semantic violations occurred relative to the adjective in between: "De eerlijke paraplu…" ("The$_{com}$ honest umbrella$_{com}$…"). This implies that in Hagoort's (2003) study – given its word by word presentation rate – the interval between the critical word (the noun) and the referent was 600 ms for the semantic violation, but 1200 ms plus an additional intervening word for the syntactic violation. Several psycholinguistic models (e.g., Gibson, 1998, 2000) would claim a significant difference in terms of integration and working memory costs between these two types of violations already on the basis of these different intervals. Furthermore, these variables may notably affect both the latency and the amplitude of the ERP components appearing during language comprehension (e.g., Hohlfeld et al., 2004; Vos et al., 2001). Accordingly, such temporal differences should be considered, not only because they affect ERPs but also because they might modulate the interplay between syntax and semantics (Just and Carpenter, 1992).

Table 1 also shows the variables violation position, word category of the violating word, type of syntactic violation, and working memory and integration costs of the violations that have been employed across the ERP experiments using factorial designs to determine the syntax–semantics interplay. The diverse results seem to reflect the range of variation across studies concerning these possibly relevant variables. Some additional variables that might also be considered, such as the language used in the study, the modality of stimulus presentation, and task demands, complete the table. Therefore, it appears that universal conclusions about the syntax–semantics interplay in sentence comprehension are not applicable. Rather, the syntax–semantics interplay appears to depend very much on the particular situation implemented in a given experimental design.

1.3. *The present study*

After having pointed out the discrepancies in current ERP literature on syntax–semantics interplay and delineating possible reasons for this situation, we report an experiment that takes into account at least some of these problems. In this experiment, syntactic, semantic, and combined violations were presented at intermediate positions, with both types of violations referring to the same point within the sentence relative to which the violation occurred. To achieve these goals, we exploited the characteristics of the Spanish language. In Spanish, most adjectives are marked for gender and number, which must agree with the gender and number of the noun they are modifying. Furthermore, in contrast with most languages used in the previous studies, adjectives in Spanish formally follow the nouns they modify. Therefore, we can have noun–adjective pairs within a sentence in which the adjective may violate either gender and/or number (syntactic violation), be semantically unacceptable (semantic violation), or violate both syntactic and semantic rules, with all violations occurring relative to the immediately preceding nouns, therefore equating them in working memory and integration costs.

The present study is the first to use adjectives as words in which the violations occur. Finally, the type of syntactic violations were morphosyntactic in nature. Examples are given below, with word-by-word translations into English and non-literal interpretation.

(a) El sentimiento$_{[masc., sing.]}$ profundo$_{[masc., sing.]}$ emociona (correct).
The feeling$_{[masc., sing.]}$ deep$_{[masc., sing.]}$ moves (=The deep feeling moves)

(b-1) El sentimiento$_{[masc., sing.]}$ profunda$_{[fem., sing.]}$ emociona (syntactic violation, gender mismatch).
The feeling$_{[masc., sing.]}$ deep$_{[fem., sing.]}$ moves (=The deep feeling moves)

(b-2) El sentimiento$_{[masc., sing.]}$ profundos$_{[masc., plu.]}$ emociona (syntactic violation, number mismatch).
The feeling$_{[masc., sing.]}$ deep$_{[masc., plu.]}$ moves (=The deep feeling moves)

(c) El sentimiento$_{[masc., sing.]}$ peludo$_{[masc., sing.]}$ emociona (semantic violation).
The feeling$_{[masc., sing]}$ hairy$_{[masc., sing]}$ moves (=The hairy feeling moves)

(d-1) El sentimiento$_{[masc., sing]}$ peluda$_{[fem., sing]}$ emociona (combined violation, gender mismatch).
The feeling$_{[masc., sing.]}$ hairy$_{[fem., sing.]}$ moves (=The hairy feeling moves)

(d-2) El sentimiento$_{[masc., sing]}$ peludos$_{[masc., plu.]}$ emociona (combined violation, number mismatch).
The feeling $_{[masc., sing.]}$ hairy$_{[masc., plu.]}$ moves (=The hairy feeling moves)

To the degree that syntactic and semantic processes are independent or interacting, we expected differential effects in those ERP components that reflect syntactic and semantic processes, respectively. We also used two different baselines for the P600/SPS component in order to compensate for a possible overlap with the preceding N400 following the procedures of Hagoort (2003) and Wicha et al. (2004) as explained above.

In summary, the present study investigated the interaction of semantic and syntactic processes during sentence reading, when both semantic as well as syntactic incongruencies could occur between a noun and an adjective.

2. Results

2.1. Acceptability judgments

Participants judged 82.5% of the correct sentences to be acceptable. Conversely, incorrect sentences containing syntactic, semantic, or combined violations were correctly judged as unacceptable in 93.5, 88.5, and 98.2%, respectively. Accordingly, subjects were well aware of the syntactic and semantic violations. Furthermore, both types of violations seemed to exert additive effects on judgment accuracy. Each type of violation increased accuracy in comparison to correct sentences, and the accuracy gain for combined violations was the approximate sum of the gains in both single violations. This impression was supported by analysis of variance (ANOVA) of percent correct judgments with grammaticality (2 levels: violation, correct) and semantics (2 levels: violation, correct) as within-subjects factors, yielding strong main effects of both grammaticality and semantics, $F(1,33) = 113.34$ and 11.47, $Ps = 0.0001$ and 0.002, respectively, but no interaction ($F < 1$).

2.2. ERP data

Figs. 1 and 2 summarize the main ERP results, showing superimposed ERP waveforms to adjectives in the control and the three violation conditions, using either a 200-ms prestimulus baseline (Fig. 1) or a 420 to 520-ms post-stimulus (LAN/N400-centered) window as a new baseline (Fig. 2).

2.2.1. Overall description of main results

In the syntactic violation condition, a small LAN appears to be present at about 470 ms after stimulus onset and with a left-frontal distribution. This was followed by a large positive deflection, the P600/SPS, maximal over parieto-central regions, starting at about 550 ms and peaking around 800 ms after stimulus onset. The semantic violation yielded an N400 peaking at about 470 ms[1], widely distributed but maximal at central leads. Interestingly, the N400 was followed by a small P600/SPS effect with latency and distribution resembling those for the syntactic condition. Although the amplitude of this P600/SPS to the semantic violation increased when the 420–520 ms post-stimulus baseline was used, its value was still noticeably lower than of the syntactic violation. Finally, combined violations yielded an N400 closely similar to the one for the semantic condition in latency, amplitude, and distribution followed by a P600/SPS. It resembled the P600/SPS from the syntactic condition in latency and distribution and – with post-stimulus baseline – amplitude. Using the prestimulus baseline, however, the P600/SPS for the combined violation appeared slightly smaller than for the syntactic violation. The small LAN observed for the syntactic condition did not seem to summate in the combined violation conditions, as was the case for the P600/SPS effects observed in the semantic violation. These visual impressions were statistically corroborated as follows.

2.2.2. Statistical analyses

ERP mean amplitude measures were quantified in 420–520 and 700–900 ms time windows following the onset of the adjective. The first window covers both the LAN and the N400; mean amplitudes for this window were computed relative to the prestimulus baseline. The second window covers the P600/SPS, mean amplitudes being computed separately relative both to the pre- and post-stimulus baseline. Overall repeated-measures ANOVAs were performed for each of these measures with within-subjects factors grammaticality (2 levels: violation, correct), semantics (2 levels: violation, correct), and electrode site (27 levels). Each overall ANOVA was followed by six pair-wise ANOVA comparisons between the experimental conditions. For the repeated-measures ANOVAs, the Greenhouse–Geisser correction was applied.

2.2.3. N400 and LAN (Fig. 1)

The mean ERP amplitude in the LAN/N400 latency window (420–520 ms) measured relative to a baseline preceding the ERP-eliciting adjective was strongly influenced by semantics as main effect, $F(1,33) = 14.82$, $P = 0.001$, and – as a trend – in interaction with electrode, $F(26,858) = 2.04$, $P = 0.098$. Grammaticality failed significance as main effect and in interaction with electrode ($Fs < 1$, $P = 0.62$), nor did it interact with semantics, $F(1,33) = 1.8$, $P = 0.18$, or with both semantics and electrode ($F < 1$, $P = 0.55$).

As to pair-wise comparisons of the experimental conditions in the LAN/N400 latency window relative to correct adjectives, ERPs differed in both semantic and combined violation conditions as main effects $Fs(1,33) = 12.49$ and 7.28, $Ps = 0.001$ and 0.011, respectively, and – marginally significant – in interaction with electrode $Fs(26,858) = 2.17$ and 2.10, $\varepsilon = 0.127$ and 0.148, $Ps = 0.089$ and 0.087, respectively. Syntactic violations differed from correct adjectives neither as main effect, $F(1,33) = 1.02$, $P = 0.31$, nor in interaction with electrode, $F(26,858) = 1.12$, $\varepsilon = 0.129$ $P = 0.34$. Thus, the apparent LAN in the syntactic violation condition could not be statistically corroborated at this level of analysis. However, a single planned one-tailed t test comparison at the F3 electrode reached significance, $t(33) = 1.72$, $P = 0.047$. The non-interaction between semantic and syntactic violations in N400 amplitude in the main ANOVA was confirmed by indistinguishable semantic and combined violations in pair-wise comparisons ($Fs < 1$ for both main effects and interactions with electrode, $Ps = 0.65$ and 0.79, respectively, $\varepsilon = 0.126$ for the latter). This remained the case even after applying planned one-tailed t tests at the F3 and Cz electrodes, $ts(33) = 0.07$ and -0.59, $Ps = 0.47$ and 0.27, respectively. Finally, the comparison of syntactic violations with semantic and combined violations yielded significant main effects, $Fs(1,33) = 4.92$ and 5.47, $Ps = 0.033$ and 0.026, respectively, but no effects in interaction with electrode ($Fs < 1$, $\varepsilon = 0.124$ and 0.127, $Ps = 0.57$ and 0.62, respectively).

[1] The N400 typically peaks around 400 ms. The large positivity preceding the N400 (probably a product of the particular material combination – noun–adjective – used in the present study) may explain the delay in the N400 observed here.

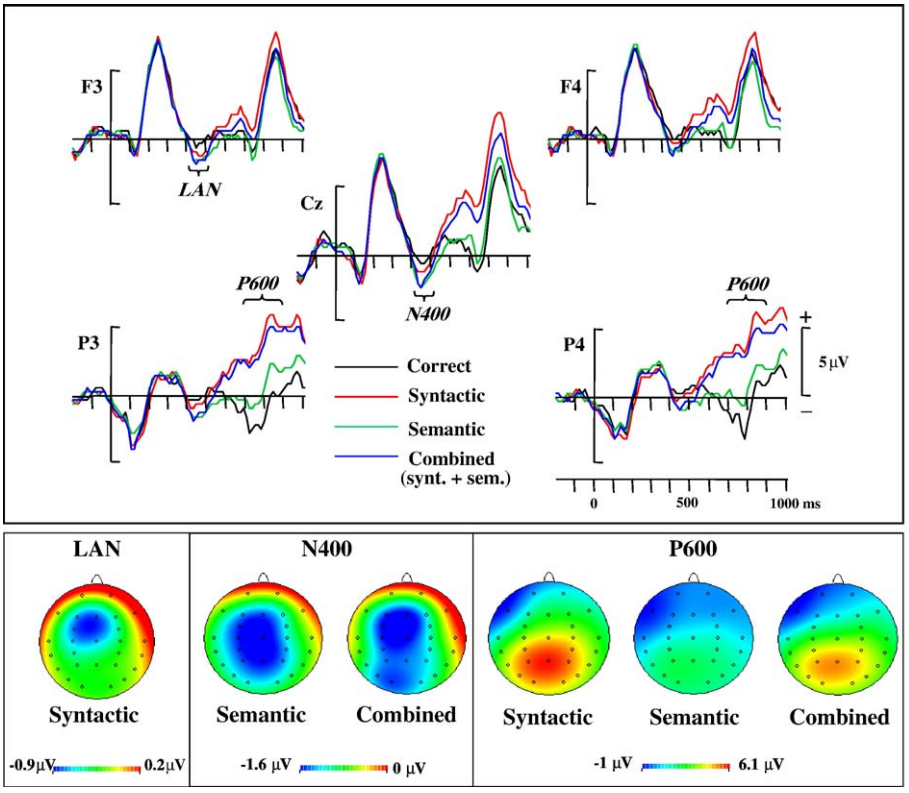

Fig. 1 – ERPs to correct and incorrect adjectives, referred to a 200-ms prestimulus baseline. Top: ERP waveforms at a selection of electrodes for correct adjectives and three violation conditions. Bottom: Difference maps of the significant effects (violation minus correct) in the LAN/N400 and P600/SPS time windows, interpolated with spherical splines (Perrin et al., 1989).

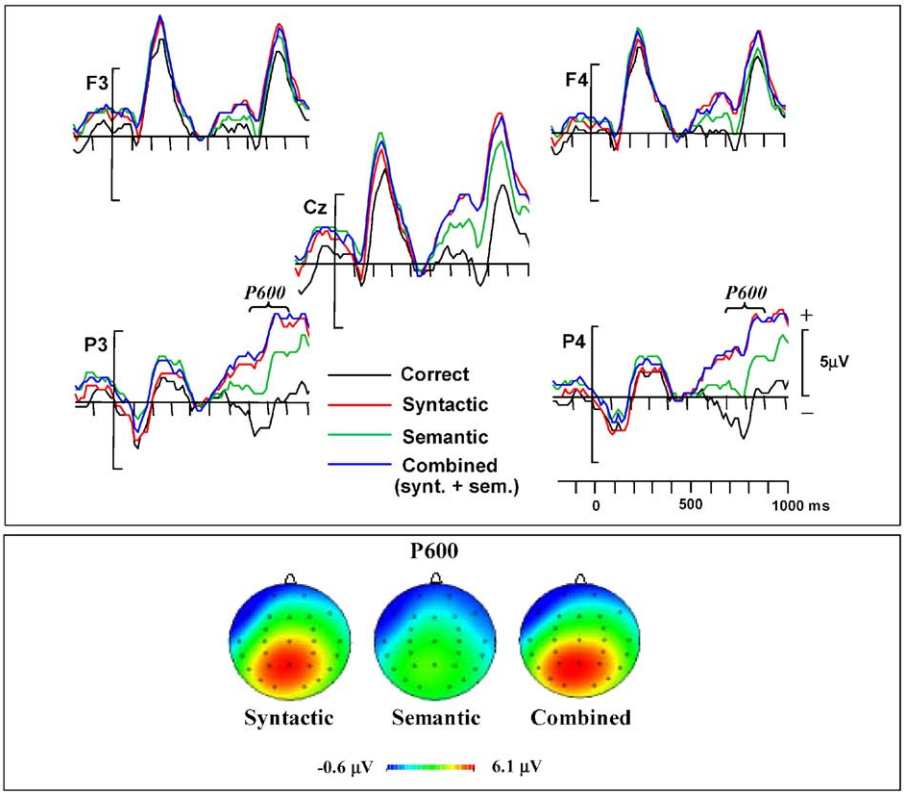

Fig. 2 – Same as Fig. 1 but recalculated to a 420- to 520-ms post-stimulus (LAN/N400-centered) window.

2.2.4. P600/SP measured with prestimulus baseline (Fig. 1)

The overall ANOVA on the mean amplitude in the P600/SPS latency range (700–900 ms) using the 200-ms prestimulus baseline did not yield a main effect for semantics ($F < 1$, $P = 0.73$), but all other effects were significant. This concerned the interaction of semantics and electrode, $F(26,858) = 7.00$, $\varepsilon = 0.126$, $P = 0.0001$, the main effect of grammaticality, $F(1,33) = 65.48$, $P = 0.0001$, and its interaction with electrode, $F(26,858) = 32.90$, $\varepsilon = 0.140$, $P = 0.0001$, and the interactions of grammaticality and semantics, $F(1,33) = 13.41$, $P = 0.001$, and of these two factors with electrode, $F(26,858) = 5.40$, $\varepsilon = 0.126$, $P = 0.001$.

Pair-wise comparisons of P600/SPS amplitudes measured with prestimulus baselines yielded the following results. Relative to correct adjectives, P600/SPS was larger for syntactic, semantic, and combined violations Fs(1,33) = 65.56, 6.81, and 43.66, εs = 0.121, 0.113, and 0.146, Ps = 0.0001, 0.014, and 0.0001, respectively, as main effects and also in interaction with electrode, Fs(26,858) = 30.38, 9.85, and 31.40, respectively, all Ps = 0.0001. P600/SPS in syntactic violations was larger than both in semantic violations as well as in combined violations as main effects, Fs(1,33) = 59.51 and 8.66, Ps = 0.0001, and 0.006, respectively, and in interaction with electrode, Fs(26,858) = 12.45 and 2.27, εs = 0.128 and 0.137, Ps = 0.0001 and 0.072, respectively, the latter interaction being a trend. Finally, P600/SPS in combined violations was larger than in semantic violations both as main effect, $F(1,33) = 29.96$, $P = 0.0001$, and in interaction with electrode, $F(26,858) = 11.55$, $\varepsilon = 0.143$, $P = 0.0001$.

2.2.5. P600/SPS measured with post-stimulus baseline (Fig. 2)

Overall ANOVA of P600/SPS amplitudes as measured relative to a baseline during the LAN/N400 latency window yielded significant effects for all factors, that is, semantics, $F(1,33) = 15.98$, $P = 0.0001$, semantics by electrode, $F(26,858) = 10.89$, $\varepsilon = 0.139$, $P = 0.0001$, grammaticality, $F(1,33) = 94.40$, $P = 0.0001$, grammaticality by electrode, $F(26,858) = 37.58$, $\varepsilon = 0.134$, $P = 0.0001$, grammaticality by semantics, $F(1,33) = 22.05$, $P = P = 0.0001$, and grammaticality by semantics by electrode, $F(26,858) = 7.14$, $\varepsilon = 0.126$, $P = 0.0001$.

Pair-wise comparisons of P600/SPS amplitude yielded the following results. P600/SPS to correct material was smaller than in syntactic, semantic, and combined violations as main effects, Fs(1,33) = 92.38, 28.80, and 62.70, respectively, all Ps = 0.0001, and in interaction with electrode, Fs(26,858) = 34.96, 17.08, and 39.09, εs = 0.131, 0.155, and 0.151, respectively, all Ps = 0.0001. Syntactic violations elicited larger P600/SPS components than semantic violations as main effect, $F(1,33) = 55.36$, $P = 0.0001$, and in interaction with electrode, $F(26,858) = 8.45$, $\varepsilon = 0.121$, $P = 0.0001$. In contrast to P600/SPS relative to prestimulus baselines, there was no difference between syntactic and combined violations as main effect or in interaction with electrode ($F < 1$, Ps = 0.99 and 0.35, respectively, $\varepsilon = 0.110$ for the latter) when post-stimulus baselines were used. Finally, when semantic and combined violations were compared, significant effects were found both as main effect, $F(1,33) = 35.24$, $P = 0.0001$, and in interaction with electrode, $F(26,858) = 11.29$, $\varepsilon = 0.133$, $P = 0.0001$.

In order to test whether the P600/SPS observed for each condition differed merely in amplitude without affecting topography, profile analyses (McCarthy and Wood, 1985) were performed. Significant differences in ANOVAs with scaled data, where possible effects of source strength are eliminated, indicate different scalp distributions (Rugg and Coles, 1995; see also Urbach and Kutas, 2002; Wilding, in press, for further discussions on the applicability of this method). For the P600/SPS time window, mean amplitudes were scaled for each subject across all electrodes, with the average distance from the mean, calculated from the grand mean ERPs, as denominator. An overall ANOVA was then performed using these scaled data and comparing the three violation conditions, yielding no significant condition by electrode interaction using the prestimulus baseline, $F(52,1716) = 1.08$, $\varepsilon = 0.008$, $P = 0.36$, as was also the case after referring the data to the post-stimulus baseline, $F(52,1716) = 0.57$, $\varepsilon = 0.112$, $P = 0.74$.

3. Discussion

The aim of the present study was to explore the interplay between syntax and semantics during sentence processing in adjectives following a noun appearing at intermediate positions of the sentence, when both types of information are equated in terms of integration and working memory costs and when the syntactic violation is morphosyntactic. For this particular condition, the first main result was that the consequences of a semantic violation on the N400 were unaffected by an additional syntactic violation. Thus, semantic integration did not seem to depend on the intactness of syntactic information. Second, the present data indicate that the reanalysis of syntactic structure was modulated by semantic information. This conclusion is based on a small but significant P600/SPS for the condition with only semantic violations. More importantly, the P600/SPS amplitude to combined violations was smaller than for syntactic violations. This was true when a customary prestimulus baseline was employed. But even when the preceding N400 amplitude was controlled for by applying a post-stimulus baseline, effects of combined violations were not equivalent to the sum of semantic and syntactic violations. That is, semantics and syntax interacted in the P600/SPS component, regardless of the kind of baseline chosen.

In line with many previous ERP studies, the LAN effect in the syntactic violation condition was unremarkable and could be corroborated only in a single planned statistical comparison. However, no trace for this component could be appreciated in the combined violation condition. It might therefore be suggested that the LAN appearing to syntactic violations vanishes under combined violations conditions, which would imply an interaction between semantic and syntactic information during this interval, thus exhibiting a functional primacy of semantics over syntax. However, the lack of a robust statistical support prevents us from considering these assertions as a firm conclusion from the present study. Nevertheless, it may be noted that similar results have

previously been reported by others (e.g., Hagoort, 2003; Wicha et al., 2004).

In contrast, we obtained a highly significant N400 effect in single semantic violation conditions. Importantly, adding syntactic anomalies to the semantic anomalies had no discernible effect on the N400 component. Therefore, it appears that semantic integration processes are not affected by morphosyntactic anomalies, at least under the conditions employed here. The situation was completely different for the P600/SPS component. The processes reflected in this component are affected by both syntactic and semantic factors in isolation. More importantly, however, these factors show interactive effects in this component. The P600/SPS in single semantic violations suggests that, at least to some extent, the revision/repair processes presumably reflected by this component are taking place also in this condition. Possibly, it is difficult to consider an adjective that is semantically meaningless as modifying the preceding noun. Thus, context-inappropriate semantic information seems to be promptly initiating structural reanalysis regardless of the initial syntactic information. Findings of a P600/SPS elicited by semantic information are not rare (e.g., Kim and Osterhout, 2005), reinforcing the idea that the integration of both semantic and syntactic information guides the processes reflected in this component (Friederici, 2002).

As regards the interaction of syntactic and semantic factors in the P600/SPS component, our results clearly demonstrate that the use of either a standard (prestimulus) or a corrected baseline is a critical factor determining either a reduction of the P600/SPS in combined violations or a match between syntactic and combined violations. Hagoort (2003) argued that "renormalization" by recalculating to post-stimulus baseline peak-to-peak measure is required in order to analyze the P600/SPS independent of the preceding N400 which in his data overlapped with the P600/SPS. However, in the present data, the N400 component seems to have faded by the time that the P600/SPS appears. In addition, using the LAN/N400 window as baseline has the effect of shifting any amplitude differences present within that window into all other parts of the ERP waveshape. This can be seen most clearly in the present data when the relatively small P600/SPS in single semantic violations is strongly magnified by the post-stimulus baseline. To take this finding seriously requires the assumption that P600/SPS starts from the level of the N400 and that N400 is present to the same degree at the peak of P600/SPS, which is hard to justify. Nevertheless, we would like to point out that both kinds of analysis clearly indicate syntax–semantics interactions at the level of the P600. It is just the pattern of this interaction that is affected by the choice of baseline. Interestingly, similar conclusions were drawn by Wicha et al. (2004), who also used both types of baselines to compute the P600/SPS amplitude.

When a standard prestimulus baseline is used, it clearly appears that the semantic information has some type of prevailing role in sentence processing as an additional semantic anomaly reduces the activity related to (single) syntactic anomalies. Apparently, then, when the adjective is tagged as semantically unacceptable, less effort may be invested to reassess the syntactic role of that word. When, by contrast, a LAN/N400 baseline is used, it appears that the consequences of a syntactic violation on the P600/SPS amplitude are unaffected by an additional semantic violation. This could be seen as indicating that P600/SPS to single syntactic violations is already at ceiling and cannot be boosted by an additional semantic inconsistency. However, using the LAN/N400 baseline, the P600/SPS was also present for single semantic violations, even increasing its values relative to those obtained using a prestimulus baseline. This in turn indicates that semantic information affects syntactic processing – as reflected in P600/SPS – to a noticeable extent, while the opposite (syntactic information affecting semantic processing as reflected in N400) cannot be held. Therefore, some kind of prevailing role of semantic information in sentence processing is again supported.

One might suggest as a possible factor accounting for the present results that, within the critical words, semantic violations could be detected earlier – at the root of the adjective – than syntactic violations — occurring at the suffix. However, it is our opinion that the relevance of this variable is minimal relative to the other factors taken into consideration here. First, the same possible problem of difference in temporal availability of semantic and syntactic information within a word can be found across all other previous ERP studies on syntax–semantics interplay. In some of these studies (e.g., Gunter et al., 1997), the ordering was reversed, that is, a syntactic violation could be detected prior to semantic violations, but, interestingly, the N400 was unaffected. Second, a visual presentation of the stimuli, as used here, should minimize any timing difference in this regard. Finally, the peak latency of the P600/SPS in our study was always the same regardless of whether the violation was purely syntactic, purely semantic, or a combination of both types.

Summarizing, in the present study, evidence for an apparently prevailing role of semantics over syntax during sentence comprehension has been observed. This kind of syntax–semantics interplay supports several theoretical proposals but contradicts others. Similarly, it is in line with some previous ERP studies but contrasts with many others. It is our line of reasoning here that universal conclusions about the syntax–semantics interplay may not be possible and that the question about the interplay between syntax and semantics during sentence comprehension may be oversimplified. In our view, this question should be posed regarding the particular circumstances to which the problem concerns.

A recent proposal by Kim and Osterhout (2005) focusing on similarities between the language processing system and the visual processing system could serve as a concluding remark, integrating present and previous results on the syntax and semantics interplay. The visual processing system is known to contain two parallel streams of processing, i.e., ventral and dorsal streams, to process object and spatial vision, respectively (Ungerleider and Haxby, 1994). These streams are thought to be independent in some respects and interactive in others. Based on a previous suggestion by Trueswell et al. (1994), Kim and Osterhout (2005) proposed that combinatory language processing might

be divided into two independent syntactic and semantic streams but with interactions between them. The functional independence of these systems would be rooted in the existence of system-specific forms of attraction, each system recognizing attractive analyses. Strongly attractive analyses would engender certainty in pursuing them even in the face of countervailing inputs from the other stream. When a system lacks a strongly attractive analysis, it would become susceptible to the influences of other knowledge sources being present. Viewed in this way, there would be no inconsistency in the simultaneous proposal of functional independence and constant interaction of the syntactic and semantic streams, the degree and the moment of interaction depending on the particular constellation of circumstances combining in a particular word within a particular sentence.

4. Experimental procedures

4.1. *Participants*

The experiment was conducted with 34 (out of 36, two of them eliminated because of recording problems) native Spanish speakers, of which 30 were females, ranging in age from 18 to 44 years (M = 21.6 years). All had normal or corrected-to-normal vision and were right-handed, with average handedness scores (Oldfield, 1971) of +87, ranging from +40 to +100. The study was performed in accordance with the Declaration of Helsinki and approved by the ethics committee of the Center for Human Evolution and Behavior, UCM-ISCIII, Madrid, Spain. Participants gave their informed consent prior to the inclusion in the study, and participation was reimbursed.

4.2. *Materials*

The set of critical items consisted of 160 Spanish correct sentences. All of them followed the same structure, [Det]–[N]–[Adj]–[V] (determiner–noun–adjective–verb). In these materials, all nouns and adjectives required to be marked either for number, gender, or both. Only 10.6% of the adjectives could also be interpreted as past participles, even though in the present sentence-structure context they could only function unambiguously as adjectives. For adjectives following the nouns in correct sentences, expectancy was 20% as obtained from 30 raters not involved in the experiment proper. In addition to the correct version of each sentence, three unacceptable versions were created. One contained a violation of the gender or number agreement between the noun and the adjective modifying that noun (syntactic violation). Gender and number violations were equiprobable. Another version of the sentences contained a semantic violation due to an unacceptable combination of noun and adjective (semantic violation). The unacceptability of the noun–adjective combinations was judged by four independent persons, and only those combinations unanimously considered anomalous were selected. The expectancy to find these semantically incongruous adjectives was zero, according to the 30 raters mentioned above. Only 11.2% of these adjectives could be interpreted also as past participles, though in the present sentence-structure context they could only function unambiguously as adjectives. Finally, sentences were created that combined both previous violations (combined violation). In all four versions of the sentences, the critical words (the adjectives) were of comparable familiarity (21 per million), according to the "Lexico Informatizado del Español" (LEXESP; Sebastián, 2000) and number of letters with Ms = 7.5, 7.6, and 7.3 for correct and syntactically, semantically, and doubly anomalous adjectives, respectively.

We also included 160 filler sentences. Half of them followed the same structure as the experimental materials, but the adjective was omitted. In the remaining fillers, a complement was appended to the structure of the experimental sentences. One fourth of the fillers were unacceptable sentences, with syntactic, semantic, and combined violations in equal proportions. Violations in the fillers always occurred in the verb, and in this material the syntactic violations consisted in subject–verb person disagreements.

All stimuli were matched in visual aspects. They were presented white-on-black on a computer monitor and controlled by SuperLab® Software. Subjects' eyes were 65 cm from the monitor. At that distance, all stimuli were between 0.7° and 1.3° high and between 1.1° and 6° wide.

4.3. *Procedure*

All sentences were presented word-by-word, with 300 ms duration per word and a 500 ms SOA, allowing 2500 ms between the end of the last word in a sentence and the appearance of the first word in the next sentence, the later being preceded by a fixation cross of 500 ms duration. Each sentence was presented in the same form: the first word began with a capital letter and the last word was presented together with a period at the end.

Participants were told that they would see a series of sentences, to be judged for acceptability by pressing a button after the last word — the one with a period. Judgments of correctness and incorrectness were given with index and middle finger of one hand; the assignment of finger to response type and usage of left or right hand was counterbalanced. Participants were advised to blink during the inter-sentence interval in order to reduce the probability of ocular artifacts in the epochs to be analyzed.

From the pool of 160 correct experimental sentences and their unacceptable versions, four different blocks of stimulus material were constructed. Each block contained 40 correct, 40 syntactically incorrect, 40 semantically incorrect, and 40 doubly incorrect sentences, taken from the experimental material. Within a given block, none of the experimental sentences was repeated and was presented only in one of its four versions (correct, syntactically, semantically, or doubly incorrect). In addition, each block contained all 160 filler sentences, making acceptable and unacceptable sentences equiprobable. All sentences within a block were presented in randomized order. Each participant viewed only one of the four blocks, and the assignment of a block to a subject was counterbalanced. The session started with a few practice trials that did not include any of the experimental sentences and short breaks were allowed during the recordings.

4.4. *Electrophysiological recording and analysis*

The electroencephalogram (EEG) was recorded from 27 tin electrodes embedded in an electrode cap (ElectroCap International). All electrodes were referenced online to the right mastoid and rereferenced offline to the average of the left and right mastoids. Bipolar horizontal and vertical electrooculograms (EOG) were recorded for artefact monitoring. Electrode impedances were kept under 3 kΩ. The signals were recorded continuously with a bandpass from 0.01 to 30 Hz and a sampling rate of 250 Hz.

The continuous recording was divided into 1200-ms epochs starting 200 ms before the onset of the adjective in the experimental materials. Artefacts were automatically rejected by eliminating those epochs that exceeded a range of +100 μV during the epoch in any of the channels. Offline, ocular corrections for blinks, vertical, and horizontal eye movements were made using the method described by Gratton et al. (1983). A visual inspection of the epochs was also carried out, eliminating those epochs that still presented artefacts after the previous rejection procedures. Epochs with erroneous judgments (i.e., correct sentences judged as unacceptable, incorrect sentences judged as acceptable) were also eliminated. Overall, the mean rejection rate was 15.3% of all epochs (24.2% of correct adjectives, 10.9% of syntactic violations, 17% of semantic violations, and 9% of combined violations).

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