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Syntactic expectancy: an event-related potentials study

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Abstract

Although extensive work has been conducted in order to study expectancies about semantic information, little effort has been dedicated to the study of the influence of expectancies in the processing of forthcoming syntactic information. The present study tries to examine the issue by presenting participants with grammatically correct sentences of two types. In the first type the critical word of the sentence belonged to the most expected word category type on the basis of the previous context (an article following a verb). In the second sentence type, the critical word was an unexpected but correct word category (an article following an adjective) when a verb is highly expected. Event-related potentials (ERPs) were measured to critical words in both sentence types. Brain waves evoked by the correct but syntactically unexpected word revealed the presence of a negativity with a central distribution around 300–500 ms after stimuli onset, an N400, that was absent in the case of syntactically expected words. No differences were present in previous time windows. These results support models that differentiate between the processing of expected and unexpected syntactic structures.

Keywords: Event-related potentials; Syntactic processing; Recognition potential; N400

Some psycholinguistic models assume that syntactic expectancy plays an important role during language processing and those grammatical structures that are more expected benefit from an improved processing [21]. An alternative theoretical approach denies any preponderance to the processing of expected compared to unexpected grammatical structures [4]. Most of the studies supporting both views are based on off-line measures. The use of event-related potentials, an online measure with a 1-ms temporal resolution might be helpful when addressing questions concerning linguistic expectancy.

Although extensive work has been conducted about expectancies related to the processing of semantic information (e.g., [3,11]) little is known about syntactic expectancy. Whenever this issue has been investigated the violation of syntactic expectancies has mainly been accomplished by presenting overt syntactic violations instead of syntactically unexpected but correct structures (e.g., [8,12]; but see [1]). Most of these studies have dealt with word category errors (e.g., presenting a verb following an article) resulting in the presence of a late posterior positivity, P600, often preceded by an early left anterior negativity (ELAN). Based on these findings Friederici and coworkers have proposed a serial stage model of language processing [5,7]. This model postulates a temporary primacy of syntactic processing. Semantic processing would take place during a second stage. During a third stage, processes concerning revision and repair of sentence structure would occur. A different approach has dealt with the processing of temporary ambiguous sentences, the so-called garden-path sentences. These studies have alternatively reported a central negativity, N400 [15], or a P600 effect [26] at the point of ambiguity resolution. It remains to be solved what happens when expectancies about the syntactic properties of a word are unconfirmed by the presence of an alternative syntactically unexpected but correct word category. This constitutes the main goal of this work.

Participants were presented with two types of correct sentences with the purpose of investigating syntactic expectancies based on word category information. The first type had the following structure: Article1-noun-verb-article2-noun.

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The second type showed a structure as follows: Article1-noun-adjective-article2-noun. Under the first type of sentences lies a very frequent structure in Spanish in which every word category is highly expected on the basis of the previous word category. By contrast, for sentences with the second structure most of the people would expect a verb to follow the adjective instead of an article as we will show later. Therefore, article2 is the critical word to which event-related potentials were measured. If syntactic expectancy does not play a role in language processing the pattern of event-related potentials should not show any differences when comparing both kinds of sentences at article2. However, if syntactic expectancy has an impact in language processing differences in brain waves should arise. We should take now into consideration the structure of both types of sentences. In the second type, in which an unexpected article substitutes the expected verb, the absence of this verb should be specially noticeable in the disruption of some processes such as thematic role assignment that are thought to be performed on the basis of semantic cues, as several studies have demonstrated [6,9,10]. Assuming such processes are preserved during the processing of sentences with the expected syntactic structure, brainwave differences in our study, if any, might be expected to arise most plausibly over components related to semantic processing.

Two components have been related to semantic processing. The processing of a word that is unrelated (although not necessarily incongruent) to a previous semantic context leads to a negative deflection that peaks around 400 ms after the onset of the unexpected word. This response is called the N400 component and its amplitude increases as a word becomes more semantically unrelated [20]. It is thought to index post-lexical integration processes, although some studies have shown its sensitivity to pre-lexical automatic processes [17,18]. A second component, the Recognition Potential (RP), peaks around 250 ms and it has shown sensitivity to the semantic content of a word (e.g., abstract versus concrete words, [23]). It shows larger amplitudes for words that are congruent to a previous semantic context and is thought to be related to lexical-selection processes [2,14]. This component benefits from the application of a paradigm, the rapid stream stimulation, in which a series of unrecognizable stimuli are inserted between the words that constitute a sentence. Although this way of proceeding increases artificiality, it has shown to be the best way of obtaining a remarkable RP [16]. Moreover, it has proved to have no impact in other language related components, such as the N400 [22].

Predictions regarding our experimental manipulation may further be specified as follows. If syntactic expectancies indeed play a role during language processing by compromising thematic role assignment, a relatively larger N400 response might be expected in response to sentences in which the syntactic expectancy of a thematic role assigner (a verb) is not matched. In this regard, previous studies violating the number of arguments associated to a transitive verb [6] or providing with two arguments competing for the same thematic role within a given clause [9] elicit N400 effects. By contrast, it is unknown whether the disruption of thematic role assignment may be able to impact other semantic-related components, such as the RP. This issue could not be addressed in previous studies [6,9] since the rapid stream stimulation was not used.

Twenty-five Spanish native students (22 female, mean age 21.2 years, range 19–27) participated in the experiment. They all were right handed, with an average handedness score of +0.82, ranging from +0.57 to +0.100 according to the Edinburgh Handedness Inventory [25]. All participants had normal or corrected-to-normal vision.

Sentences were arranged in pairs such that the same critical word (article2) was used across sentence types. A total of 30 sentences with an expected syntactic structure were constructed (Article1-noun-verb-article2-noun). From each of these sentences a second version was made (Article1-noun-adjective-article2-noun). These versions had an unexpected syntactically correct structure attained by presenting article2 after the adjective instead of the most highly expected word category item (a verb). Nouns, verbs and adjectives were two- or three-syllable frequent words. Verbs were all regular and conjugated in past tense. Sentences were presented in lower case letters with the exception of the first letter of the first word of each sentence that was presented in upper case. An example of each sentence type is given below with the critical word in italics (an English translation is provided):

(1) Expected word category: El luchador ganó *el* combate/The fighter won *the* combat
(2) Unexpected word category: El luchador ganador *el* combate/The winning fighter *the* combat

Syntactic expectancy of the target article was previously assessed by presenting two versions of a questionnaire to 20 subjects other than those participating in the event-related potentials experiment. The first questionnaire included fragments of 15 first type sentences (up to the verb) and 15 second type sentences (up to the adjective). The second one included the remaining 15 sentences of both types. Participants were instructed to complete sentence fragments. The syntactic category of the first word that subjects provided after each fragment was considered. In first type sentences 67% were continued with an article, which constituted the most expected word category. In second type sentences only 1% of fragments were continued with an article (most fragments, 77%, were continued with a verb). This data confirmed that second type sentences showed an unexpected word category item at the point of article2.

As noticed in the introduction, words on each sentence were visually presented embedded in a stream of unrecognizable stimuli. These stimuli were made by cutting verbs, nouns and adjectives of the experimental sentences in '*n*' portions (*n* = number of letters that formed a given word minus one). These portions were repositioned so that they formed a pattern of unrecognizable stimuli including also unrecognizable letters.

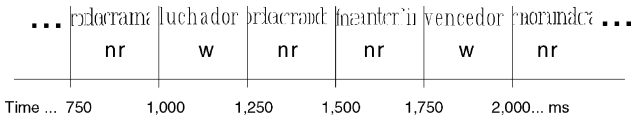

Fig. 1. The stimulation procedure is exemplified. "W" refers to words, whereas "Nr" refers to non-recognizable stimuli.

Participants were tested in a single experimental session. They were presented with the 60 sentences in a word by word fashion, together with the proportional amount of non-word stimuli. They were instructed to read sentences for comprehension and to answer to probe questions when required. A practice block was allowed to participants before the experimental session begun. None of the sentences used in the training session were experimental sentences. Stimuli were presented according to the rapid stream stimulation procedure [13,27] with a stimulus onset asynchrony (SOA) of 250 ms.

After six or seven non-recognizable stimuli (this number randomized) the first word of the sentence appeared. The remaining words came up consecutively after a variable number of non-recognizable stimuli (2 to 4, this number randomized) until the completion of the sentence. Again, six or seven non-recognizable stimuli were presented between the last word of a sentence and the first word of the new sentence. Every 4 to 6 sentences participants were presented with a comprehension probe question about the contents of the immediately preceding sentence. Half of them had an affirmative response whereas the remainders had a negative one. Participants gave yes–no answers and were allowed to blink. After doing so, they had to press a button in order to keep on with stimuli presentation. Fig. 1 exemplifies the stimulation procedure.

The electroencephalogram (EEG) was recorded with 59 tin electrodes embedded in an electrode cap (electroCap International). Scalp locations were: Fp1, Fpz, Fp2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, PO1, POz, PO2, PO4, PO8, O1, Oz, O2 and left mastoid, all referenced to the right mastoid. Bipolar horizontal and vertical electrooculograms (EOG) were recorded for artifact rejection purposes. Electrode impedances were kept under 3 KΩ. The signals were recorded continuously with a bandpass from 0.01 to 50 Hz and a digitization sampling rate of 250 Hz.

The continuous recording was divided into 1224 ms epochs, beginning 200 ms before every critical word (article2). Visual inspection of data was carried out in order to delete artifacts and noticeable eye movements or blinks. Offline correction of smaller eye movement artifacts was also made, using the method described by Semlitsch et al. [28]. In all electrodes, originally M2-referenced data were re-referenced offline to the average of the mastoids. ERP averages were aligned to a −200 ms pre-stimulus baseline.

Repeated-measures Analyses of Variance (ANOVAs) were performed for amplitude comparisons between expected and unexpected word categories. Amplitude was measured as the mean amplitude of a particular time interval. To avoid loss of statistical power when repeated-measures ANOVAs are used to quantify large number of electrodes [24] analyses on amplitude were conducted on a selected sample of 38 electrodes: Fp1, Fpz, Fp2, AF3, AF4, F5, F1, Fz, F2, F6, FC5, FC1, FCz, FC2, FC6, C5, C1, Cz, C2, C6, CP5, CP1, CPz, CP2, CP6, P5, P1, Pz, P2, P6, PO7, PO1, POz, PO2, PO8, O1, Oz, and O2. These ANOVAs included two factors: word type (2 levels: syntactically expected/syntactically unexpected) and electrode (38 levels). The Geisser-Greenhouse correction was always applied. Finally, pair wise comparisons on amplitude were further performed, over the electrodes showing the highest amplitude for the Recognition Potential and the N400 components separately.

On average, participants responded correctly to 98.1% of the comprehension probe questions (range 83–100%). Overall performance seems to be excellent, indicating that subjects were attending to the experimental stimuli and processing them for meaning.

Visual inspection of the grand-averaged ERPs suggested the presence of RP as well as N400 effects (see Fig. 2).

RP peaked about 234 ms after stimulus onset for both syntactically expected and unexpected critical words. Statistical analyses on amplitude measurements were conducted on the 206 to 262 ms time window (mean latency ± 28 ms) revealing significant main effects of word type ($F_{1,24} = 7.9$; $p = 0.01$) and electrode ($F_{37,888} = 20.6$; $p < 0.0001$). Pair wise comparisons were applied at PO7 electrode that shows the largest RP amplitude. The analysis revealed lack of differences between syntactically expected and unexpected words ($F_{1,24} = 0.4$; $p = 0.5$). Actually, the amplitude was fairly identical, approximately 3 μV, in both cases. The topographic maps in the 206–262 ms interval are shown in Fig. 3.

N400 effects were noticeable between 300 and 500 ms after stimuli onset, especially at central electrodes. An ANOVA applied at this time interval revealed significant effects of word type ($F_{1,24} = 17.2$; $p < 0.0001$) and electrode ($F_{37,888} = 19.8$; $p < 0.0001$). Pair wise comparisons at Cz electrode confirmed the significant difference between syntactically expected and unexpected words ($F_{1,24} = 14.9$; $p = 0.001$). Fig. 4 shows the topographic distribution of N400 after subtracting the activity evoked by syntactically expected words from that evoked by unexpected words. A centrally distributed negativity with a slight left-lateralization can be observed.

Data reported in the present experiment clearly indicate the existence of some differences in the processing of expected and correct but unexpected word category information. Such differences are noticeable by the presence of a negativity around 300–500 ms after the onset of the article2 in those sentences in which a verb was expected instead (e.g., "The winning fighter *the* combat"). This effect was absent in sentences in which participants expected an article2 to follow the verb (e.g., "The fighter won *the* combat").

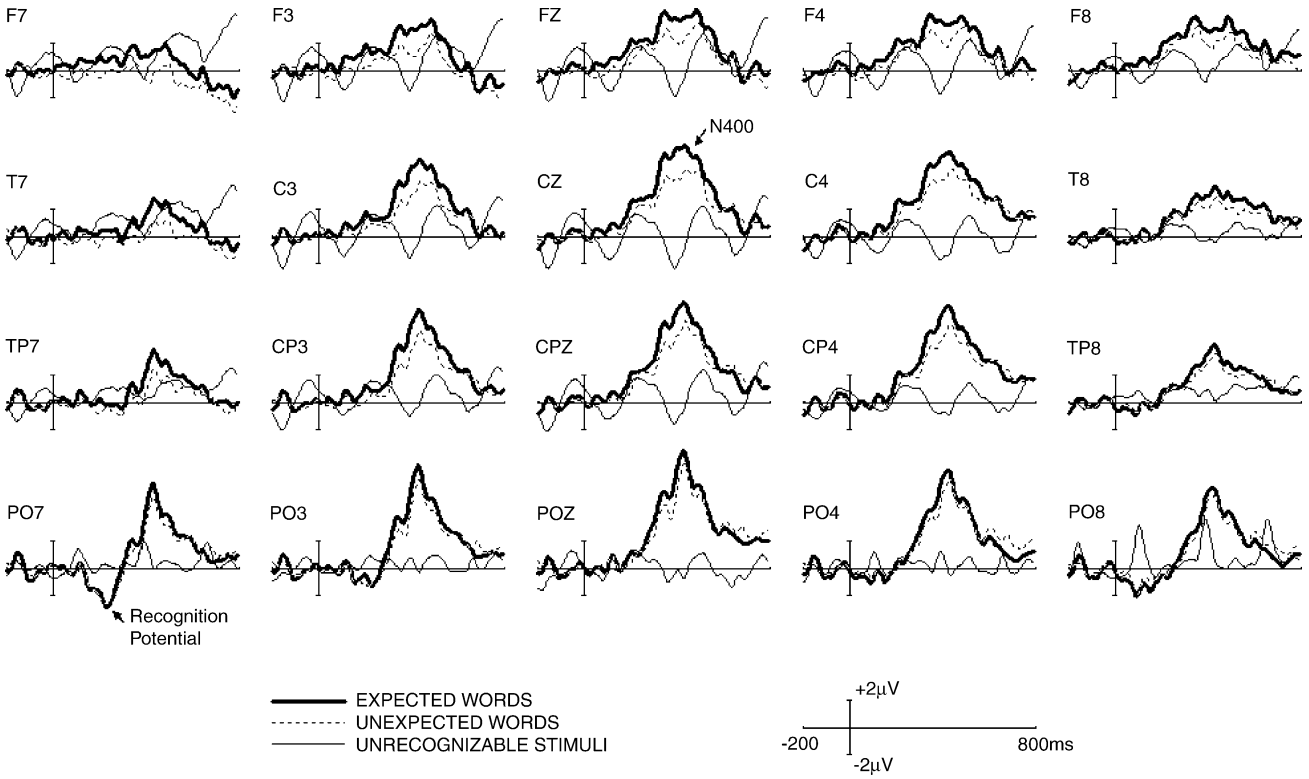

Fig. 2. Grand-average ERPs corresponding to syntactically expected and unexpected words at a sample of electrodes after the application of a low-pass (20 Hz) digital filter. A Recognition Potential is noticeable for both types of stimulus at parieto-occipital electrodes. Also, the comparison between syntactically expected and unexpected words yields a clear N400 effect.

As noticed in the introduction, we hypothesized that if an effect of expectancy exists, it should affect semantic-related components because the absence of the expected verb would preclude thematic roles assignment, a process that is essential in order to understand a sentence. The disruption of such processes has shown to elicit comparable N400 effects to the one reported here in at least three previous studies. Gunter and Friederici [10] found an N400 response with a centro-parietal distribution elicited by a word category violation that was obtained by replacing the obligatory noun in a prepositional phrase by a verb form. On the basis of their data, Gunter and Friederici speculated that this effect could be explained by appealing to the fact that prepositions are thematic role assigners, so the N400 response they found would be reflecting semantic expectation for the assignment of a particular role. In a different study, Friederici and Frisch [6] reported an N400 component with a central bilateral distribution. This response was elicited by violations in the number of arguments of transitive verbs, which disrupts processes at the thematic role level. Finally, Frisch and Schlesewsky [9] found an N400 with a central distribution elicited by violations of the thematic relations between arguments in a sentence. Despite the existence of some differences in the topography of the N400 in these studies, it seems that these effects all have a close functional significance. The rather atypical more anterior topographic distribution of the N400 reported in our study could be explained by the rapid stimuli presentation rate. In fact, it has previously been shown that increasing word presentation rate causes N400 to display a rather frontal distribution [19]. Alternatively, some authors have shown that with increasing SOA the N400 shifts towards more anterior electrode locations [18].

Relevant to our results, prior studies have shown N400-like effects to close class words (articles in Spanish) when they mismatched the grammatical gender of a noun highly expected on the basis of previous semantic context [29,30].

It is interesting to notice that expected and unexpected words did not differ by the time the Recognition Potential peaks. This component has shown to be influenced by semantic variables [22,23]. Our current view on the RP is that it reflects lexical selection processes, although other researchers postulate that the RP reflects the stage of lexical access related to the processing of word form [2]. A null effect such as the one reported here should always be taken with caution. In our opinion the absence of an effect in our study does not challenge either view on the functional significance of the RP. It would be interesting for future research to investigate whether the RP is sensitive to overt syntactic violations or not. This could be helpful in order to disentangle issues such as the modular [4] or interactive [21] nature of early language processing stages.

The relationship between RP and thematic role processing remained to be explored. Our data might suggest that such processes take place at later stages than those reflected by

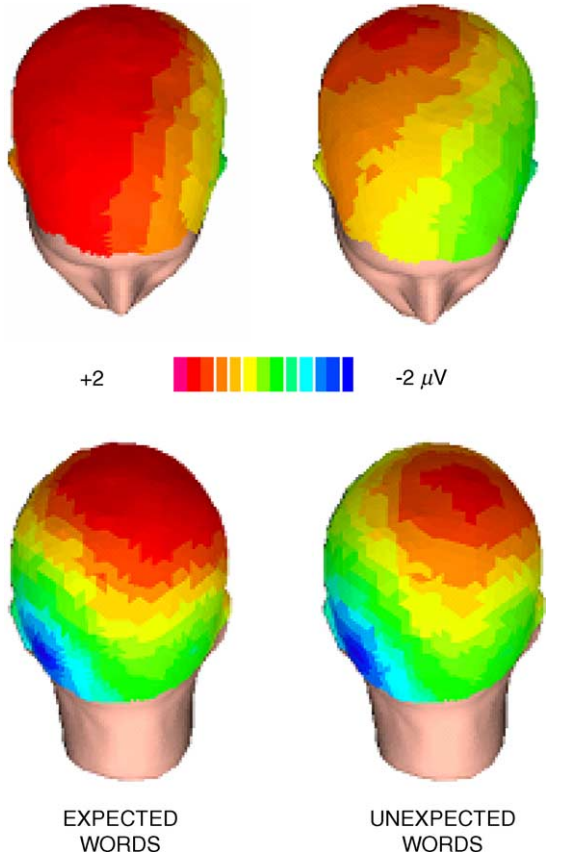

Fig. 3. Topography of the Recognition Potential evoked by syntactically expected and unexpected words across the total array of 58 cephalic electrodes. Maps represent mean values for the 206–262 ms time interval.

the RP. Also, on the basis of our data we could speculate with the possibility that expectancies about word category information do not influence those early stages reflected by RP during language processing. It would not be until a later stage of processing, when post-lexical integration processes are taken into account, that syntactic expectancy exerts influence in language processing.

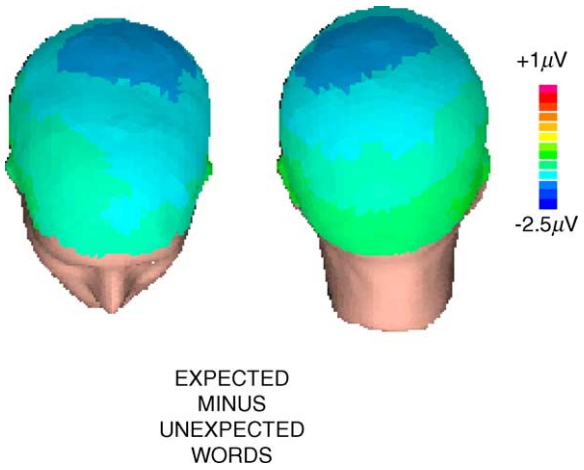

Fig. 4. Topographic map corresponding to N400 effects after subtracting activity evoked by syntactically expected words from activity evoked by syntactically unexpected words in the mean values for the 300–500 ms time window.

Results as those provided in present research might be taken into account when formulating general language processing models. Current proposals are mainly based on the processing of overt syntactic violations, such as the serial stage model by Friederici and coworkers [5,7]. In our view such proposals should also consider findings on the processing of correct grammatical structures. However, this kind of studies is still scarce. Therefore, it seems still premature to draw strong conclusions on this issue and further research is needed.

In sum, data from this experiment provide support to those psycholinguistic theoretical approaches that assume that expected syntactic information is easier to process than syntactic information that is unexpected on the basis of the previous structure of the sentence [21].

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